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THE VALUE OF MICRO-FOSSILS IN PETROLEUM EXPLORATION[1]

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President Ball has asked me to point out the value in subsurface correlations of the fossils that may be obtained in oil-well drilling, and especially of the Foraminifera. In endeavoring to meet his request, I first made a number of inquiries by letter of those familiar with the latter group of fossils, and then spent three days in the several paleontologic laboratories at Houston where Foraminifera have been used successfully during the past four years.

It was at the Dallas meeting led by President Deussen that Paleozoic foraminifers began to attract attention as possible guides to underground correlation, and at that time I pointed out something as to their values for this purpose, and, especially in private conversation, testified to their abundance in late Mesozoic and Cenozoic marine strata. As early as 1913, however, Dr. E. T. Dumble had been looking around for someone to make a stratigraphic study of the small fossils found in the Texas Gulf Coastal area, but was not successful in this until four years ago, when Miss Richards, now Mrs. Applin, and as well Miss Ellisor and Miss Kniker, began their foraminiferal studies for subsurface correlations. State Geologist Udden, of Texas, has since 1917 also been using foraminifers in stratigraphic correlations, and has educated several persons to use them in subsurface work. Houston is now the most active center for foraminiferal lore,

[1] Read before the Association, Houston meeting, March 27, 1924.

and here in at least four different laboratories this knowledge is successfully applied. The leading authority on the Foraminifera, Dr. Joseph A. Cushman, of Sharon, Massachusetts, is having marked success in working out the late Cretaceous stratigraphy of the Tampico region of Mexico for the Marland Company, and Dumble tells us that G. Dallas Hanna is using foraminifers with "splendid results" in correlating the Cenozoic strata of California for the Pacific Oil Company. From this it is apparent that, in America, Foraminifera are no longer on trial as guide fossils in underground correlation, and to strengthen this conclusion excerpts from a number of letters relating to this matter may be presented.

From the pioneer laboratory in this line, that of the Rio Bravo Oil Company, in charge of Dr. Dumble, which began work in September, 1920, I learn that the paleontologists

> had very little knowledge to start with and had to build up their own methods, but now the three laboratories of Houston working in unison have accumulated a mass of data which very definitely settle the question as to the utility of Foraminifera in stratigraphic correlations.

Last year Dumble made the following statement in print:

> The rock materials proved to be of minor value for our purpose. . . . . It was found, however, that the well materials, whether clays, gumbo, shale, or sands, frequently carried minute forms of mollusca, many Foraminifera, and other microscopic forms, some of which were distinctive enough in themselves and of sufficiently limited range to be determinative. Correlations based upon Foraminifera are fully as dependable as any secured from the study of macroscopic fossils.[1]

Wallace E. Pratt, of the Humble Oil and Refining Company, wrote me about their most interesting results as follows:

> We have been engaged in micro-paleontology over a period of about three years, having been interested principally in the sediments of the Gulf Coastal plain. We started with practically no information as to the character of the geologic section beneath the surface . . . . , although we assumed it to be analogous to the section shown by the outcrop rocks farther inland. We knew nothing as to the age or character of the source rocks of our petroleum supply, nor did we know even the age of the reservoir beds. . . . . Today, after comparatively brief experience, we can state with fair accuracy the age and character of our reservoir beds, the age and character of our source rocks, and we

[1] E. T. Dumble, "Oil Well Stratigraphy of the Gulf Coastal Plain," *Pan-American Geol.* (March, 1923), pp. 95–100.

can know in advance what character of material we may expect to penetrate at a given depth, and all this with some degree of accuracy. . . . .

In spite of the foregoing statements, we are still unable to say exactly what we can do in the way of precise correlation with micro-fossils. We place most dependence on Foraminifera, lithology being variable, and megascopic fossils difficult to obtain in identifiable form, but we check against both megascopic fossils and lithology. We have been able to correlate zones of 400 or 500 feet thickness over areas hundreds of miles in extent. We have not distinguished zones or horizons of less than about 200 feet in thickness. . . . . While many species of Foraminifera as recognized at present range widely through the geologic column, we are finding hitherto unrecorded features of ornamentation, etc., which range less widely, and together with the character of the assemblage, enable us to distinguish and correlate Miocene, Oligocene, and various formations of the Eocene and the Cretaceous. We have been able to make subdivisions of the hitherto undifferentiated Oligocene and Jackson solely on the basis of foraminiferal character.

R. F. Baker, of the Texas Company, writes:

We can safely correlate wells in the Texas Coastal Plain from the Louisiana state line south to the Colorado River of Texas. This area includes all of the oil-producing fields of the Coastal Plain. Within this extensive region the foraminiferal faunas are the same in every field and stratigraphic correlations are easily and safely made. Furthermore, even though the Oligocene and Miocene foraminifers of the Isthmus of Panama are quite different from those of Texas, yet the general aspect of the former is such that with our knowledge of those of Texas, we can with these fossils readily make stratigraphic correlations between the two regions.

From Miss H. T. Kniker, in charge of the paleontologic laboratory of the Texas Company, I have the following information:

In well drillings large fossils, including large forams, are usually absent. Nor are ostracods, barnacles, or the spore cases of Chara of much value. We therefore practically base our paleontologic correlation on the small Foraminifera, the Cenozoic forms of which are much more restricted geographically than are the large fossils. On the other hand, the Upper Cretaceous forams are very persistent, and one fauna with about a dozen characteristic species has been found at all places from Arkansas through Louisiana and Texas into central Mexico.

In the Coastal Cenozoic formations from the late Eocene (Jackson) into the Miocene, all of the various formations having forams can be traced from field to field. Even though the Foraminifera change with latitude and with variations in the rock character, yet on the basis of their combinations it is comparatively easy to correlate the strata from place to place. Examination of thousands of well samples has shown which species have limited vertical ranges and

therefore which forams can be relied on to make correct stratigraphic correlations. We have learned to do this even on single species, and all of our correlations are made in the main on undescribed forms.

Alexander Deussen answered my questions as follows:

Our experience has been that in general it is possible to recognize with a fair degree of certainty the larger geologic divisions upon the basis of their Foraminifera and lithology. For example, we recognize with a fair degree of certainty Miocene, Oligocene, and Jackson in our coastal wells. Further inland, we recognize Cook Mountain and Midway of the Eocene. Along the Cretaceous-Tertiary contact we recognize in most instances the various formations of the Upper Cretaceous. On the whole, I am inclined to the opinion that the work is well worth while, and sufficiently valuable to justify its cost.

These quotations show clearly that most of the petroleum companies using minute fossils as stratigraphic guides—and this means mainly Foraminifera—are having splendid results.

From this testimony as to the actual results obtained from the study of micro-fossils, let us turn to a more general consideration of the fossils themselves. First, however, something must be said regarding the minerals found in the sandstones, and their time value in correlation.

PETROLOGY

As yet American geologists exploring for petroleum pay almost no attention to the mineral assemblages composing the sandstones encountered in oil-well drillings, and it is in the sandstones that the paleontologic methods of age determination so often fail, because in them there is usually an absence of fossils, either large or minute. Therefore the sandstones should also be washed free of their muds and the mineral fragments gathered as aids to age discrimination. This study is well worth trying out in each petroleum field to see what stratigraphic values may be recorded in the minerals present. In Great Britain, Holland, Trinidad, and elsewhere, the petrologic method has proved of value.

A small but good textbook on this subject is by H. B. Milner, entitled *An Introduction to Sedimentary Petrography* (London: Murby & Co., 1922). This is mainly a laboratory manual, telling how to separate out of the sands the various minerals, and how to determine them. The book diagnoses fifty-four kinds of minerals

so obtained, forty of which are commonly met with in British sediments.

FOSSILS IN SUBSURFACE CORRELATIONS

We are now ready to discuss, but only in a broad way, the kinds of organisms found as fossils and the testimony they bear as to the kind of environment in which they lived. It is a well-known fact that the different kinds of life in existence at present are restricted to given places. Some live only in fresh water, others in shallow seas or in the depths of the oceans. In other words, all life is more or less localized by temperature and by the nature of its habitat. This being true for the living world, every fossil should likewise bear witness as to its former environment, and the marine kinds usually show at once whether they lived in the oceans or in their shallow extensions, the seas. Therefore a fossil of a marine kind is unmistakable evidence that the rock in which it occurs is of the seas or oceans. Furthermore, all marine life of the geologic ages is localized by temperature and by depth of water, and much of it also is habituated to sand, mud, or rocky bottoms. The swimming and floating kinds when dying will fall upon any kind of bottom, and all of these restrictions and dispersals are shown by the fossils in the rocks. Hence marine fossils like foraminifers, corals, bryozoans, brachiopods, or cephalopods are unmistakable evidence that the rocks in which they occur as natives are of marine origin, since none of these with fossilizable parts are known in fresh waters. On the other hand, if the rock formations abound in land plants, or land animals like reptiles and mammals, the evidence, as a rule, is just as clear that both the deposits and fossils are those of the land, the records either of rivers, lakes, or wind accumulations. Of course, some formations, like those laid down near the shore of a sea, will have the marine faunas mixed with land forms, but as a rule the life derived from the land is easily detected. Even the bay, estuary, or brackish-water deposits are easily told by the small variety of their contained life, its smaller size and often depauperate condition, and by the mixed faunal elements.

After a century of work by the paleontologists of the world, it is not necessary to elaborate for geologists why it is that stratigraphy is based essentially upon the evolution of life as collected from the

formations outcropping at the surface. Those who need this information will find it stated in almost any textbook on paleontology or historical geology. We will therefore proceed at once to the kinds of whole fossils obtainable in deep well cuttings, since it is these upon which subsurface correlations must depend. As fragments of large species, and even the young of these, are not as a rule identifiable, and as microscopic life is very frequently common in late Mesozoic and all of Cenozoic marine strata, it is naturally upon this micro-life that the geologist seeking petroleum is most dependent. The most abundant representatives of this usable micro-life are Foraminifera, Ostracoda, and Bryozoa. At times, however, other kinds of fossils are also present and may be of considerable time value, for example, the small spines of echinids, Radiolaria, and sponge spicules, but as to these fossils not much dependable information can be given at the present time, and each worker must learn what local dependence can be placed upon these isolated occurrences. Therefore we will go on to the consideration of the correlation values of the commoner kinds of micro-fossils.

BRYOZOA

There is not the slightest doubt as to the precise time value of Mesozoic and Cenozoic bryozoans in subsurface correlations, and their value in this matter has been abundantly tested by Canu and Bassler on the basis of collections made from outcrops along the Atlantic and more especially the Gulf Coastal areas east of Mississippi River. In this region bryozoans are often very common, and as the individuals composing a colony are minute and their calcareous structures generally highly ornate, a small amount of marl will often yield several tens of kinds of species. West of the Mississippi, however, the experience of the drillers for petroleum has shown an almost complete lack of bryozoans in Louisiana and Texas, and they are therefore too rarely found in this region to be of value in subsurface correlations. When they turn up in the more marine Eocene and Oligocene cuttings, their study should be undertaken, and chiefly on the basis of Canu and Bassler's monumental work entitled *North American Early Tertiary Bryozoa*.[1] Here 742 forms are described,

[1] F. Canu and R. S. Bassler, *U. S. Nat. Mus. Bull. 106*, text and plates, 877 pages, 162 plates, 279 text figs., 1920.

and the book teems with diagrams and plates of photographic illustrations showing the species as one sees them under the microscope.

As Bassler has had more experience in the collecting and distinguishing of Cenozoic bryozoans than any other paleontologist, I asked him to give me briefly his opinion as to the time values of these organisms in subsurface correlations. His reply was as follows:

> The two orders of Bryozoa, Cyclostomata and Cheilostomata, prevail in the Mesozoic and Cenozoic, but of these the Cyclostomata have less value, because in order to make most exact determinations, specimens preserving the ovicell are necessary, a condition which commonly does not exist in well drillings. The Cheilostomata, on the other hand, are most useful because they can be accurately determined from minute fragments and all of their characteristics can usually be ascertained even though only a few individuals or zooecia are preserved. Fortunately they are very abundant in the Upper Mesozoic and throughout the Cenozoic, while the Cyclostomata are on the wane during this time. These Cheilostomata not only mark limited time zones through wide stretches of country, but the various structures preserved on the zooecium are indicative of the depth of water, temperature, nature of the ocean bottom and character of the sea in which they live. Canu and I are bringing this out from our studies of the recent Gulf of Mexico Bryozoa compared with the Coastal Plain Cenozoic faunas. The Avicularia, for example, mark, according to their size, the depth of water and its condition, whether quiet or disturbed. Furthermore, the calcification of the frontal of the zooecium is in relationship with the composition of the sea water, and even the larvae of the Bryozoa give data as to their habitat, for the larvae of different groups select totally distinct objects upon which to affix themselves and start growth of the colony.
>
> Regarding the wide geographic distribution for a limited time, the Bryozoa follow the same rules as other fossils and indicate, like them, the ocean from which they originated. The same Jacksonian and Vicksburgian zones, for example, can be followed across several of the Gulf states, and in the Atlantic Coastal Plain the identical bryozoan faunas can be recognized as far as the formations containing them can be discriminated. The various Miocene formations are particularly noted for this feature. The marine Midway formation is likewise characterized by the same widespread bryozoan faunas. All these facts have been tested out in numerous well samples that have passed through my hands.

OSTRACODA

Paleontologists have long known that ornate ostracods are of much time value, and that they are often excellent guide fossils to

limited portions of the marine Paleozoic formations. This has recently been demonstrated on a large scale by Ulrich and Bassler.[1] These minute bivalved crustaceans have continued to live in considerable variety ever since the Ordovician, but even though I knew that ornate forms are common in the Miocene of Maryland, I was not aware of their abundance in the well cuttings of Texas. The paleontologists of Houston, however, often find highly ornate forms, having both valves in connection, and they are well aware that most of them have limited time valves, but as yet, for want of time, little use has been made of them. It is to be hoped that a monograph of the Texas species will be forthcoming, since they will be seen to have correlation values next to those of the Foraminifera. Ostracoda and Foraminifera, because of their abundance, are the fossils so far known to be of most value in subsurface correlations west of the Mississippi River. From time to time the bryozoans will surely turn up, and with this triad of life all the better correlations will be made.

FORAMINIFERA

It has long been the experience of petroleum workers that large fossils are but very rarely present in rotary and churn well drillings, and even though in rock cores they are often common, yet cores are so seldom obtained that dependence cannot be placed upon the large fossils in subsurface stratigraphic correlations. Therefore dependence must be upon the microscopic forms of life, and in the Gulf Coast area the minute foraminifers, which are generally present in great abundance, have so far proved to be of the greatest value. Their general presence in well cuttings is, in fact, due to their small size, since the average diameter of the small foraminifers allows twenty-five individuals to the inch, and many are so small that one hundred can lie side by side in the same length. Hence in half a thimbleful of washed well cuttings there may be many hundreds of specimens, and each local assemblage may have from a few species to many hundred forms.

The discovery by the workers in the Houston paleontologic laboratories that Foraminifera are of marked stratigraphic value

[1] E. O. Ulrich and R. S. Bassler, "Paleozoic Ostracoda: Their Morphology, Classification, and Occurrence," *Maryland Geol. Surv. Silurian Volume* (1923), pp. 271–391, pls. 36–65.

was somewhat surprising, since paleontologists generally, and especially European workers with the group, have held that the species of these organisms are usually so long-lived as to have almost no limited time value. The large species of the Foraminifera, on the other hand, have been demonstrated over and over again to have limited time ranges, and they are used successfully in stratigraphic correlations by the paleontologists of the United States Geological Survey, and have long been so used by European workers. However, since the large foraminifers are seldom found in well cuttings, they have little practical value in petroleum mining, and are here dismissed with some references to the literature.[1]

Dr. Vaughan was asked by President Wrather to present at the Shreveport meeting of this society his views "On the Relative Value of the Species of Smaller Foraminifera for the Recognition of Stratigraphic Zones," and on the basis of data used by him, he came to the following perfectly natural conclusion. He says:

> In any event, 25 per cent is about the maximum percentage of the smaller Foraminifera to which any stratigraphic significance may be attached, and it is more probable that the significant percentage is between 3 and 12. In order to use the species belonging to this percentage, between 3 and 12 per cent of the entire fauna, these species must be singled out and clearly discriminated from the 88 to 97 per cent of the fauna which does not possess zonal value. . . . . From available evidence similar faunas of small Foraminifera are indicative rather of similarity in ecologic conditions than of identity in age.[2]

Finally he makes the striking statement that it "appears very doubtful if there is a zonal distinction" of value among the Foraminifera for the discrimination of geologic horizons.

This was altogether too much reflection upon Miss Richards' pets, and after a prolonged study of them, with daily testings as to her stratigraphic conclusions, she made at the time the following rejoinder:

> We began to hunt for something on which we could rely as a definite means of formational determination and then discovered the possibilities of the

[1] J. A. Cushman, "The American Species of *Orthophragmina* and *Lepidocyclina*," *U. S. Geol. Surv. Prof. Paper 125-D* (1920), pp. 39–108, pls. 7–35; T. W. Vaughan, "Studies of the Larger Tertiary Foraminifera from Tropical and Subtropical America," *Proc. Nat. Acad. Sci.*, Vol. 9 (1923), pp. 253–57; C. W. Cooke and J. A. Cushman, "The Correlation and Foraminifera of the Vicksburg Group," *U. S. Geol. Surv. Prof. Paper 133*, 1923.

[2] T. W. Vaughan, this *Bulletin*, Vol. 7 (1923), pp. 517–30.

Foraminifera. . . . . Even a small fragment of rock in a fossiliferous zone carries a whole fauna of forams. . . . . An intensive study of several thousand samples of materials submitted from wells in Texas, Mexico, and Louisiana has proved to the satisfaction not only of our own company, but the Humble, the Texas, and other workers in this field that the major divisions of geological time —the Pliocene, Miocene, Oligocene, Jackson, Claiborne, Wilcox, Midway and various divisions of the Upper and Lower Cretaceous—carry foraminiferal faunas which are sufficiently distinct and clearly defined to give us no difficulty in separating them easily.[1]

In my judgment, the "ladies have it," since they demonstrate daily that most of the foraminifers that come into their hands have more or less distinct time values. Vaughan, on the other hand, is also correct in his statement that from 3 to 12 per cent, and at best only 25 per cent of any Cenozoic foraminiferal assemblage, *as defined in the literature of the subject*, is restricted to a limited time, but he is wrong in his implication that from 88 to 97 per cent of the Foraminifera do not possess *local zonal value*.

Let me restate this matter in more detail, so that all may understand where lie the difficulties of the diametrically opposed conclusions. Vaughan looks at Foraminifera in their world-distribution as recorded in the literature, and therefore if a Cretaceous or Cenozoic species, as usually defined in the books, is still living today in any of the oceans, he concludes that such species have *nowhere* any geologic correlation value. In this implied conclusion he is undoubtedly wrong. The Texas workers, on the other hand, are not much concerned with the world-distribution of the foraminifers that they find in the well cuttings, but study *intensively*, not only the species, but also the local assemblages as they come to them. Moreover, they have learned to discriminate the species much more closely than is usually the case in the literature. As a consequence, most of the material consists of new species or new varieties, and it is this splitting of old species into new and more localized ones that has made it possible to use the Foraminifera in detailed stratigraphic correlations. Even when the same form recurs at more than one horizon in a single well, or in different wells, the foraminiferal assemblage is studied along with such other fossils as may be present. Dependence is not placed, therefore, upon *percentages* of the living Foram-

[1] Esther E. Richards, *ibid.*, pp. 530–31.

inifera in any faunule, upon which Vaughan lays so much stress, but consideration is given, not only to the species present but to their combination in the faunules as well. In other words, the workers take note, not only of what is present, but equally of what is absent, when contrasting different faunas of the same time or of different times. Furthermore, all this is checked by the ascertained superposition of faunas that have been learned, along with the character of the rock in which they occur. All of the evidence at hand is studied and weighed in the light of intensive study of the micro-faunas of the Gulf Coast region, checked against an ascertained succession of faunas as worked out of rock cores. The results are furthermore proved to be correct by the independently secured results of the various workers.

I also wrote Dr. Cushman for his opinion on the value of these organisms in subsurface correlations. The following is his reply:

> The greatest success that I may have had over others in stratigraphic correlations on the basis of Foraminifera is partly due to the very thing for which I have been criticized, especially by European workers on the forams; that is, the tendency to split species to a much greater degree than has been done by others. The time value of forams, however, is entirely dependent on this splitting, for putting together species which are of short range into one long one would entirely defeat the purpose of close correlation. . . . . I have felt for a long time that the forams are just beginning to come into their own, as far as their value in economic work is concerned, and I am very sure that careful, trained workers, who have powers of close discrimination, would prove that they are one of the most valuable sources of information for close correlation in economic work.

F. Chapman in his well-known textbook, *The Foraminifera* (London, 1902), states that

> Foraminifera are largely influenced by the temperature of the water in which they live, and therefore it will not be surprising to find that different latitudes have their own peculiar assemblages of species, and that the foraminiferal faunas of the colder regions are in many respects unlike those of the warmer areas. This difference is naturally more noticeable in the case of the bottom-living species from *shallow* water.[1]

We may add here that it is temperature and other environmental conditions that control foraminiferal distribution, and not depth and pressure of the waters.

[1] *Op. cit.*, p. 278.

A single locality in warm waters about present coral reefs will yield up to 300 kinds of Foraminifera, and in the Adriatic Sea a single ounce of washed sand may have as many as 6,000 individuals. In cold waters, the variety of Foraminifera is small, and at Woods Hole, Massachusetts, there are only 28 kinds in waters down to 100 feet of depth, whereas in the Keys of Florida (at Dry Tortugas) the shallow waters have 145 forms. Brackish-water Foraminifera usually have but a few species, and the shells are generally thinner and more delicate. In size, the small foraminifers will average 25 to the inch arranged linearly, and from this range down to 100 individuals to the inch. Finally, it should be said that it is the calcareous-shelled Foraminifera, either of perforate (glassy-looking) or imperforate (porcelanous-like) kinds, that are of value in stratigraphic correlation. The agglutinated or arenaceous types have but little time value, although even here there are some notable exceptions.

Since there can be no longer the slightest doubt as to the great value of micro-faunas in subsurface stratigraphic or zonal determinations, let me state the procedure followed in the paleontologic laboratories of Houston. The rock material is carefully collected in the field as to depth in the well, and as to whether it is (1) a core, (2) material attached to the driller's tool, or (3) the washings from a churn or rotary cased or encased well. Core rocks have fossils from but one level, and the material attached to the bit probably is also always of one limited horizon, but the cuttings from an uncased well cannot be used in building up a standard faunal sequence against which other wells are to be correlated.

In the laboratory, the rock material as it comes from the field is broken up and soaked over night in water, then washed with the fingers and the muddy water decanted away until the granular residue no longer discolors the water. It is then dried and spread upon a black surface and examined under a binocular microscope magnifying about thirty diameters. In this way all the good fossils are picked out of the washed débris and placed in a cell of a glass slip like those used by microscopists. The great value of this method is that each faunule of loose specimens is always kept together, and at any time may be restudied or compared with other

lots. For each well there is then prepared a descriptive log as to the species found in each zone, along with the rock character and other physical evidence.

It has already been stated that when small Foraminifera are present—and they are more often at hand than absent—there is no difficulty in making out their Pliocene, Miocene, Oligocene, Eocene, or Cretaceous age. It should be said here, however, that there are strata barren of all fossils, and that these are at times many hundreds of feet thick. When a fossiliferous formation is thick, or a thinner one is rich in foraminifers, the paleontologists can usually readily see faunal differences in about each 400 feet, and it is not rare to determine zones 200 feet thick or even less. When all the evidence, both faunal and lithologic, is fully studied, and the fossil assemblages are large and quickly changing, there is every reason to believe that stratigraphic zones tens of feet thick will be correlatable from well to well. On the other hand, as the circle of correlation widens, the faunas change, since some species vanish and new ones come in. Then, too, the rock nature changes and with it more or less of the faunas, so that the paleontologist is constantly called upon to work out other standards for correlation. It is this everlasting fossil and lithologic change that perplexes the beginner working with subsurface micro-faunas, and a determined stratigraphic sequence of such cannot be obtained by the paleontologist in much less time than six months. This estimate, moreover, assumes that the worker with fossils has been previously trained in paleontology, and has, above all, a good eye to distinguish differences between species, and a long memory to retain the shapes of the fossils seen. Since Applin, Kniker, and Ellisor now have several years' experience along with thousands of determined records on file that are easily accessible, I am told that, from washings received in the morning, they frequently by night determine the zone at which the drill stands. A well-equipped laboratory like that of the Humble Company usually reports on twenty-five lots per day. No one who depends wholly on depth, lithology, and thickness of formations can correlate safely, because the formations change exceedingly rapidly in thickness toward the salt domes, and the breaks between them become greater and greater. This irregu-

larity of stratal deposition is due to these domes rising periodically ever since Jackson time. It is from the Foraminifera that nearly all of the present knowledge of the intricate subsurface stratigraphy of the salt domes has been determined.

The subsurface foraminiferal faunas of the Cenozoic of east Texas are usually small, there being in each one anywhere from a few species up to something like fifty forms. Laterally the assemblages change rapidly, with variation in the lithology, and from the shore with brackish waters toward the gulf with more and more normal marine waters. Under the same environmental conditions, they also change more rapidly from north to south than they do from west to east; this is due to temperature conditions, since on going south from the Gulf states more and more tropical conditions are encountered toward southern Mexico. On the other hand, the Upper Cretaceous foraminiferal faunas are more equable in character, and usually they are also far larger in number of species, because at this time the water was uniformly warmer than at any time during the Cenozoic, excepting the late Eocene and most of the Oligocene. In the Tampico area of Mexico the uppermost 1,000 feet of the Cretaceous (Velasco formation), Cushman tells us, has about 700 forms of Foraminifera. Finally, Foraminifera are more common in calcareous rocks like limestones and marls than in aluminous muds or shales, and are least abundant in sands. The sandstone zones at times make up one-half the depth of oil wells. In the late Eocene and all of Oligocene time, it is the rule to find an abundance of micro-fossils, since most of these strata are of a calcareous nature. Furthermore, the waters of these times were warm and in consequence a greater variety of species is present. In other words, living foraminifers are known to be very sensitive to environmental conditions, such as differences of temperature, depth, salinity, and clarity of water. The great bulk of living forms (more than 2,000 kinds) have their homes on the bottoms of the marine waters, and fewer than 25 kinds in 6 genera are pelagic or floaters. When the floating forms, mainly *Globigerina*, dominate a fossil fauna it means either open-sea connections or decided currents from the open sea.

The foraminiferal studies of the Miocene of northeastern Texas have brought out a very peculiar condition regarding the species encountered. Here the outcrops of the Miocene are now known to be of fresh-water deposition, and yet they have marine Cretaceous foraminifers and Gryphæas of Comanchean time. The same conditions are true for the inland subsurface Miocene, but toward the gulf in the area northeast of Houston and Galveston every now and then there occur zones of brackish water that yield a few foraminifer species of undoubted Miocene age, along with fragments of oysters. At first, this age contradiction of the superposed zones was unexplainable, but after a time Cushman and the Houston paleontologists noticed that the Cretaceous species were always much worn or broken, showing that the specimens were washed out of the Cretaceous and redeposited during Miocene time. Furthermore, these Cretaceous strangers always occur in golden-colored sands. Even when normal marine Miocene sediments are encountered, there will be small foraminifer faunas, since this time is one of "fairly cool waters" even in the latitude of Florida (Cushman). Therefore, Texas workers with fossil foraminifers must always be on their guard in dealing with Miocene formations, and in fact there is always the possibility of these strangers appearing in the shoreward deposits of any age. It is their minute size that makes their redeposition as determinable fossils possible. Even though redeposited foraminifers occur in younger formations, this fact when once known takes on a time value and can be used locally in determining the age of the strata in which such fossils occur.

On the outcrops the Miocene has a thickness of about 800 feet, but eastward it has been learned from the introduced and native Foraminifera that this formation thickens greatly, to the unexpected depth of about 3,000 feet. Since the petroleum occurs below the Miocene, mainly in the Oligocene, it is evident that even the derived Cretaceous Foraminifera have their value in exploring and drilling for oil.

SOME NOTES ON THE UPPER CRETACEOUS PALEOGEOGRAPHY OF MONTANA

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INTRODUCTION

A knowledge of the geographic conditions existing within the area now known as Montana in Upper Cretaceous time can only be gained by a study of the sediments laid down in that period. These sediments have been examined and described and their geologic relations are well known, but so far as the writer is aware the geography of the region at the various stages in Upper Cretaceous time has never been described except in a very general way in textbooks of historical geology. The discussion in these notes will be limited to the area east of the Rocky Mountain front.

The Rocky Mountain front as selected for present purposes is shown on the accompanying maps. From south to north the line follows the northeast flank of the Beartooth and Absaroka ranges from the Montana-Wyoming line northwestward to the vicinity of Chestnut, thence northward along the east flank of the Bridger Range to Castle Mountain. From Castle Mountain the front is drawn along the southeast and northeast flanks of the Little Belt Mountains to a point south of Great Falls, thence westward to the Rocky Mountains and northwestward along the east flank of the Lewis Range through Glacier National Park to the international boundary. The area now occupied by the Rocky Mountains in Montana was, during at least a part of Upper Cretaceous time, the scene of sedimentation. The present state of knowledge, however, does not permit an intelligent attempt to discuss the paleogeography of the mountainous portion of the state.

The generalized geologic section for the Upper Cretaceous of Montana on page 555 is given for convenience.

GEOLOGIC HISTORY

Before the invasion of the Montana region by marine waters at the beginning of Upper Cretaceous time the country was a monotonous plain where the streams carried only fine sediments. These are seen as the red, gray, and sandy shales which, in every

TABLE I

System and Series	Formation	Thickness in Feet	Characteristics
			Montana Group
Upper Cretaceous	Bearpaw shale	35–1200	Dark marine shale containing many concretions and local sandstones
	Judith River formation	200–550	Consists typically of three members: an upper ledge-making sandstone; a middle member of soft sandy shale, thin sands, and local coal beds; and a lower member of ledge-making sandstone
	Claggett formation	350–700	Dark marine shale below grading upward into sandy shale and lenticular sandstone
	Eagle sandstone	0–380	Made up of three members where typically developed. The upper member is a massive gray sandstone, the middle member is shale, sandy shale, and local coal beds. The lower or Virgelle member is a massive cliff-making sandstone.
			Colorado Group
	Shale undifferentiated	720	Dark-gray marine shale containing concretions of iron stone and limestone. Sandy toward top
	Frontier? formation	520	Predominantly gray shale. The Mosby sandstone 5 feet thick is 188 feet from base. Contains streaks of bentonite and sharks teeth above Mosby sandstone
	Thermopolis shale	900	Dark-gray shale, sandy at base
	Dakota sandstone	10–80	Brown or gray sandstone. Thin bedded above. Massive at base

section seen by the writer, directly underlie the Dakota sandstone. There is no apparent unconformity or disconformity between the Upper and Lower Cretaceous strata in Montana. The first sediments deposited by the invading Upper Cretaceous sea were sandstones, the Dakota and its equivalents. All of Montana east of

the Rocky Mountain front was submerged from the beginning of Colorado time to the beginning of Eagle time, but the conditions of deposition were not uniform during all this period. Most of the formations of the Colorado group are made up of muds deposited in comparatively shallow water. The Mowry shale contains an extraordinary number of fish scales which suggest that the conditions under which it was deposited resulted in the death of a great number of fish. The peculiar lithologic character of the Mowry shale is probably due to the inclusion in it of a large proportion of material

FIG. 1.—Outline map of Montana showing greatest emergence in Eagle time. Hatched area was submerged.

of volcanic origin, and the extent of the Mowry indicates that the volcanic activity was widespread. South of the Highwood Mountains in Cascade County there is an ash bed 30 feet thick somewhat nearer the base of the Colorado group than the Mowry is usually found. Weed[1] states that the ash is here overlain by sandy shales containing numerous impressions of fish scales. The ash bed weathers to a gray color very similar to the color of the Mowry on exposure.

That there were any land areas in Montana east of the present Rocky Mountain front in Frontier time is improbable. The Fron-

[1] W. H. Weed, "Fort Benton Folio, Montana," *Geologic Atlas U. S. Folio 55*. U. S. Geol. Survey, 1899.

tier and its equivalents are coarser textured in southern and central Montana than the sediments stratigraphically above and below them. In the Little Rocky Mountains the equivalent of the Frontier consists in part of light-colored fossiliferous sandy limestone.

At the beginning or slightly after the beginning of Montana time the sea withdrew from a large area in Montana, leaving as a beach deposit the massive Virgelle sandstone, the lowest member of the Eagle sandstone. The withdrawal of the marine water was followed by a period of continental deposition of yellow and gray

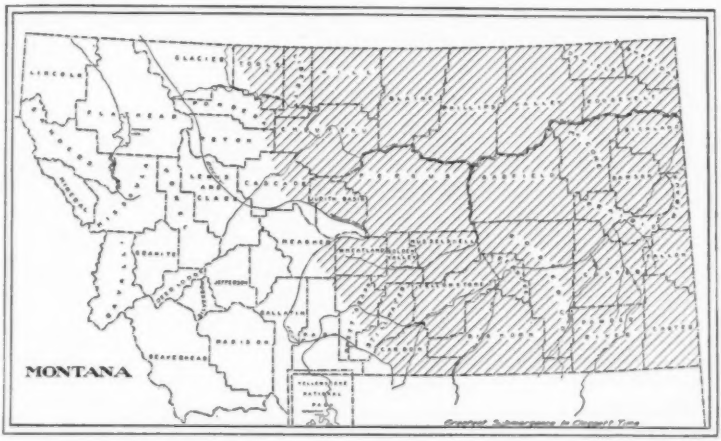

FIG. 2.—Outline map of Montana showing greatest submergence in Claggett time. Hatched area was submerged.

sandy shale and local coal beds which are in some places of minable thickness. This is the middle member of the Eagle. The reincursion of the sea at the end of Eagle and the beginning of Claggett time resulted in the deposition of another massive sandstone, the top member of the Eagle. The accompanying paleogeographic maps show that a part of the area which had been covered by marine water in Upper Colorado time was not resubmerged in Claggett time (Figs. 1 and 2). In areas not submerged in Claggett time the Eagle sandstone consists only of the sandstone of emergence, the Virgelle sandstone, which is succeeded above in the northwestern

FIG. 3.—Outline map of Montana showing greatest emergence in Judith River time. Hatched area was submerged.

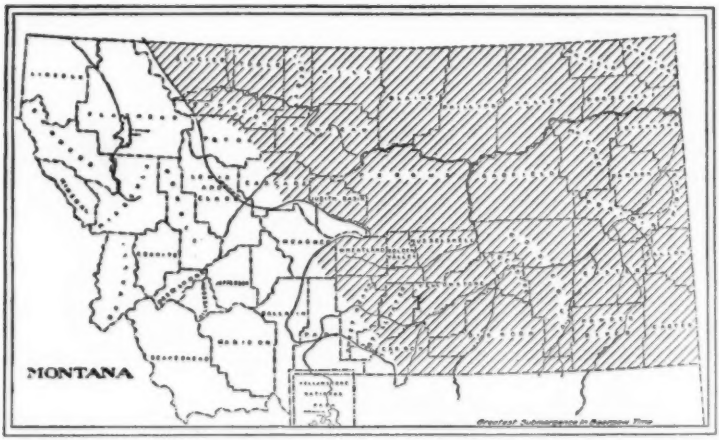

FIG. 4.—Outline map of Montana showing greatest submergence in Bearpaw time. Hatched area was submerged.

part of the region under discussion by the shales, irregular sandstones, and local coal beds of the continental Two Medicine formation and the Crazy-Absarokee Mountains area by the andesitic beds of the lower part of the Livingston formation. The Claggett sediments are shale and lenticular sandstone which are lighter colored and more arenaceous than those of the Colorado or Bearpaw, indicating that the Claggett sea was probably shallower than either the Colorado or Bearpaw seas.

At the end of Claggett time the sea withdrew from large areas which became the scene of the continental deposition of sand, sandy and clay shale, and thin local coal beds. These continental beds make up the Judith River formation in central Montana, but this formation is marine in its eastern part. The map shows the approximate land and sea areas at the time of greatest emergence in Judith River time (Fig. 3).

At the end of Judith River time and the beginning of Bearpaw time the sea began an encroachment westward, the Bearpaw submergence being more widespread than that of the Claggett (Fig. 4). The Bearpaw shale is dark and fossiliferous and contains very little sand except along its western edge. The extent of the Bearpaw submergence is shown on the map.

At the end of Bearpaw time the final emergence of the region occurred and the continental sediments of the Lance formation were deposited.

CHEMICAL CHARACTERISTICS OF CALIFORNIA PETROLEUMS[1]

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The petroleums of California are very often assumed to belong to one general class, and to differ from each other only in the relative proportions of light and heavy constituents. This is far from the truth. Even if we neglect such incidental constituents or impurities as sulphur, naphthenic acids, and nitrogen compounds, which of themselves often govern the choice of a crude for a given use or purpose, and if we set aside a number of very interesting oils of unique properties, and our small production of true paraffin oils, we still find two sharply defined classes of crudes—the cold test crudes and the waxy crudes.

In each of these two classes we find the widest range of properties and weights—oils ranging from heavy tars, containing large quantities of asphalt and little or no volatile products, to light limpid oils containing a great deal of gasoline and relatively little asphalt. But regardless of the weight and the corresponding relation between light and heavy constituents, these two groups may be distinguished clearly in almost all cases, not merely by the presence or absence of paraffin wax, but by other characteristics which apparently have no direct connection with the wax content, and which indicate a distinct difference in origin.

It is not intended here to discuss the ultimate origin of our petroleums, nor the age of the rocks from which they are produced. Nor is it possible in so brief a paper to go into the subject of chemical characteristics from a scientific standpoint. The subject which has for us the greatest present interest is that of the value of various crudes, which is determined by the quantity and quality of products which they yield, and by the ease and cheapness with which they may be handled in the refinery.

[1] Read before the Association at the Los Angeles meeting, September, 1923. Manuscript received by the Editor, November, 1923.

TABLE I

THE LOCATION OF OIL DEPOSITS IN CALIFORNIA*

Index	Location	Production	Group 1 Gravity Min.	Group 1 Gravity Max.	Group 2 Gravity Min.	Group 2 Gravity Max.	Group 3 Gravity Min.	Group 3 Gravity Max.	Group 4 Gravity Min.	Group 4 Gravity Max.
1	Humboldt County	None					24°	40°		
2	Point Arena	Asphalt Beds								
3	Colusa County	Seepages							15°	
4	Bolinas Bay	None	22°							
5	Contra Costa	None							30°	
6	Half Moon Bay	None					33°	52°		
7	Watsonville	Very Small	15°	18°						
8	Moody Gulch	Very Small					43°			
9	Santa Cruz	Asphalt Beds								
10	Vallecitos	None			22°	33°				
11	Bitterwater	None							43°	
12	Coalinga	Large	11°	25°	28°	33°			15°	41°
13	Lost Hills	Moderate			30°					
14	Devils Den	Very Small	14°	25°					?	
15	Belridge	Moderate	14°	25°						
16	McKittrick	Moderate	12°	20°						
17	Midway	Very Large	11°	24°	24°	33°				
18	Maricopa	Large	9°	20°						
19	Buena Vista	Large			26°					
20	Elk Hills	Large			?	35°				
21	Wheeler Ridge	Small		25°						
22	Comanche Point	None							14°	
23	Kern River	Large	12°	17°						
24	Porterville	None							15°	
25	Tiber or Edna	Very Small	9°	12°						
26	Sta. Lucia Mts.	Asphalt Beds								
27	Huasna	Asphalt Beds								
28	Guadalupe Hills	Asphalt Beds								
29	Casmalia	Small	9°	13°						
30	Santa Maria	Moderate			17°	35°				
31	Cat Canon	Small			9°	15°				
32	Lompoc	Small			14°	18°				
33	La Patera	Asphalt Beds								
34	Summerland	Very Small	12°	15°						
35	Ventura River	Small			35°					
36	Ex-Mission	Very Small	19°	30°	20°	33°			20°	35°
37	Ojai	Very Small	12°	14°	18°	27°				
38	Sespe	Very Small	13°	...	19°	35°				
39	Hopper & Modelo	Very Small	14°	...	...	29°				
40	Castaic	None					25°			
41	South Mountain	Small			25°	32°				
42	Montebello	Small			18°	28°				
43	Torrey & Eureka	Very Small			20°	30°				
44	Pico & Wiley	Very Small					24°	40°		
45	Newhall	Small	12°	18°	17°	31°				
46	Simi Canon	Very Small	No Analyses							
47	Santa Susana	Very Small			33°					

* The numbers refer to the map. Where no production is indicated in the third column it is understood that oil has been found but that there is no commercial production. The range of gravity shown covers analyses in the writer's records but does not necessarily indicate the full range of gravity in the field.

TABLE I—*Continued*

Index	Location	Production	Group 1 Gravity Min.	Group 1 Gravity Max.	Group 2 Gravity Min.	Group 2 Gravity Max.	Group 3 Gravity Min.	Group 3 Gravity Max.	Group 4 Gravity Min.	Group 4 Gravity Max.
48	Callequas	Very Small							13°	15°
49	Los Angeles City	Small	11°	15°						
50	Salt Lake	Moderate			10°	23°				
51	Redondo-Torrance	Moderate			11°					
52	Compton	Coming in			Light					
53	Signal Hill	Very Large			17°	27°				
54	Santa Fe Springs	Very Large			22°	35°				
55	Whittier	Moderate	14°	22°						
56	Montebello	Large			18°	28°				
57	Puente Hills	Very Small			23°	30°				
58	Brea Canon-Olinda	Large	15°	25°	18°	28°	32°	35°		
59	Richfield	Large			15°	25°				
60	Santa Ana Canon	Small			20°					
61	West Coyote	Large			30°					
62	East Coyote	Large			16°	25°				
63	Huntington Beach	Large			15°	27°				
64	Newport	None			10°					

GENERAL CLASSIFICATION

In California there are at least four distinct classes of crude oil, of which the two mentioned above (1 and 2 of following list) make up almost the entire present production. These are: (1) asphaltic crudes free from wax, (2) asphaltic crudes containing wax, (3) paraffin crudes almost identical with certain typical Pennsylvania oils, and (4) heavy crudes free from both asphalts and paraffin.

The oils in group 3 are unimportant in volume of production and promise to remain so. The oils in group 4 are not now produced in quantity but there seems to be an excellent prospect for a considerable yield of this quality in the future.

LOCATION OF DEPOSITS

Table I lists the more important locations at which each class of crude is found. The classes are not confined to any definite areas, but occur at random, often in close juxtaposition, apparently following geological conditions which are extremely diverse in this region of late and severe movement. The accompanying map (Fig. 1) indicates the various sources of each class or group in such manner as to obviate the necessity for description.

DISTINCTION BETWEEN GROUPS 1 AND 2

Groups 1 and 2, which together may be taken as the typical California oil, have many properties in common. They contain a

FIG 1

relatively large proportion of asphalt, which of course is much greater in the heavy than in the light, and in this respect they resemble the Mexican and some of the Gulf Coast crudes. They usually contain a relatively large proportion of sulphur which,

however, is much more firmly combined than in most sulphur-carrying oils. Their volatile products have a relatively low boiling point for any given gravity, and conversely, a cut of any given boiling range is considerably heavier than a corresponding cut from paraffin crudes. As a type they run high in naphthenic acids and in nitrogen compounds. Their hydrocarbons seem to be of the same general nature; easily acted on and decolorized by acid; prone to form oil-soluble reaction products, and therefore difficult to wash clean; and readily crack down to middlings but only with difficulty to gasoline. The hydrocarbons are said to run very high in naphthenic and in aromatic bodies, but though numerous individual bodies belonging to these groups have been isolated, the usual method of determination and of classification into "naphthenic" and "aromatic" crudes seems rather vague and uncertain.

The distinctions between these two groups lie mainly in the proportioning of the commercial constituents, and while these distinctions may at first glance seem somewhat tenuous, they are in fact very real and of considerable importance to the refiner. They may perhaps be best illustrated by comparing proximate analyses of typical samples of the same gravities (Table II).

TABLE II

	Low Cold Test Oil	Waxy Oil	Low Cold Test Oil	Waxy Oil	Low Cold Test Oil	Waxy Oil	Low Cold Test Oil	Waxy Oil	Low Cold Test Oil	Waxy Oil
Gravity of Crude....	11.7°Bé.	11.0°	16.0°Bé.	16.2°	20.3°Bé.	20.5°	27.8°Bé.	26.3°	33.9°	33.4°
Source of Crude.....	Newhall	Cat Canon	Coalinga	Lompoc	West Midway	Santa Ana Canon	Puente	Signal Hill	Coalinga	Santa Fe Spgs.
Analysis No.....	7440	4472	4455		6426		4417	16437	411	14385
	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent
Gasoline at 60° Bé....	0.0	0.0	0.0	1.9	1.0	6.4	3.5	15.5	11.4	22.8
Distillate at 52°.....	0.0	3.0	0.0	4.2	3.4	4.0	10.0	0.0	8.0	0.0
Kerosene at 42°.....	0.0	6.0	0.0	15.4	12.1	7.4	11.0	13.5	35.8	17.5
Middlings.....	45.4	32.2	35.0	36.4	29.2	26.9	45.0	33.5	43.8	36.7
Lubricants.....	30.4	27.9	45.0	20.1	33.6	24.7	12.5	19.5	8.0	12.0
Asphalt.....	24.6	31.5	20.0	22.1	21.7	28.0	18.0	24.0	1.0	11.0
Sulphur.....	0.7	6.9	0.8	4.4	0.5	1.8	0.4	1.0	0.05	0.46

From these analyses the following observations may be drawn: (1) Gravity for gravity, the yields of asphalt and of gasoline are much higher from the waxy than from the cold test crudes, the latter running more to lubricants and to fuel distillates or middlings.

(2) The lubricating cut from the wax oils is rendered practically valueless, in the present state of refining practice, by the wax, which is in most cases so perfectly amorphous as to be quite difficult to remove, and in some cases is precipitated as an inseparable colloid or gel. On the other hand the lubricating cut from the non-waxy oils, while it has the great advantage of a naturally low cold test (usually below zero in the less viscous fractions) has along with this a very poor viscosity curve; that is to say, for any given viscosity at high temperature the viscosity at low temperature is abnormally high. In this respect the wax-bearing lubricants from group 2 oils are markedly superior when the wax has been removed. (3) The proportion of sulphur in the waxy oils is notably higher (as a rule, and for any given gravity) than in the cold test oils, a fact which can hardly be fortuitous, and which is probably directly connected with the greater yield of asphalt from this group. The proportions of nitrogenous and acid bodies is generally lower in the waxy than in the cold test oil.

To all appearance the heavier members of the cold test group are the result of partial evaporation of lighter members of the same group. If we compare a large number of analyses of oils of this class, having progressively lower gravities, we find that corresponding analyses would be obtained by gradually topping off the more volatile constituents of the lightest members, the proportion of the heavier constituents increasing in proportion to the reduction in bulk.

On the contrary, in group 2 we find appreciable quantities of gasoline and distillate in some of the heaviest crudes, such as contain high proportions of asphalt. This condition does not permit ascribing the high asphalt content to evaporation of lighter constituents, as it is rather the middlings which are absent. We may assume that each of these various grades represents an original oil variety, which is highly improbable. Or, oxidation or dehydrogenation of an originally lighter crude by contact with sulphur at a rather elevated temperature would produce asphalt in quantity without necessarily eliminating the volatile elements. Finally—and this is almost certainly the explanation in at least one case—a tarry crude free from volatile constituents may by contact with

wet gas from a lighter crude take up a small proportion of gasoline, thus producing a crude of abnormal properties.

REFINING OF COLD TEST OILS

Although some light waxy oil is found in the San Joaquin Valley fields, the bulk of their production lies in the cold test class, and is handled in a manner not exactly identical with that practiced with other American crudes. In the following description no distinction will be made between the lighter and the heavier members of this class, though, as will appear from the analyses above, practically no crude of this class heavier than 20° is suitable for refining unless asphalt and lubricants are the desired products.

Gasoline and engine distillate, if present, are distilled off in any convenient manner, no particular method nor precautions being required. The one exception to this statement is that when the sulphur runs high, as it usually does, care should be taken to hold distillation temperatures as low as possible. The sulphur compounds appear as a rule to have a higher boiling point than even the kerosene cut, but are quite subject to heat decomposition, so that if excessive temperatures are carried, and particularly if there is severe local superheating of the crude, sulphur compounds and unstable cracked hydrocarbons will be carried over, and the gasoline will be unstable in color. With proper care it is usually possible to make a water-white, sweet, stable, and non-corrosive gasoline from crudes of this class by simple redistillation or dephlegmation, without any chemical treatments, which is seldom possible with the crudes of group 2. Gasoline of navy specification and of the best carburetting quality can be made from group 1 crudes at as low a gravity as 52° Bé., with modern methods of dephlegmation. This gasoline is rich in carbon but burns slowly and completely, gives exceptionally little pre-ignition trouble, and is, in the writer's opinion, one of the best motor fuels known. This does not mean that very bad gasoline may not be made from such crudes if unskilfully handled.

The *kerosene cut* from crudes of this class is of medium quality only, and this quality varies materially with the percentage of sulphur in the crude. Better stocks are, therefore, usually obtainable

from the lighter crudes, which as a rule contain proportionately less sulphur, though excellent lamp oil can be made from the less than 1 per cent of stock yielded by 14-gravity crude. Where distillation is carefully conducted, a water-white and sweet oil of export grade may be made from these crudes by a light treatment with 66° acid followed by very careful neutralization and washing. The tar produced by acid treatment is readily re-dissolved in the oil, and more than usual care must be taken to free the oil mechanically from tar prior to neutralization. When a first-quality burning oil is required, recourse must be had to fuming acid, or to other of the treatments described in connection with kerosene from group 2 crudes. Kerosene being but little in demand, this cut is usually split into a heavy explosion engine distillate and a fuel distillate.

Fuel distillates of various grades follow the kerosene, or may be the initial products from very heavy crudes. In making these products from sulphurous oils, the temperature necessarily rises to the point where the sulphur alcohols begin to decompose, and consequently these distillates will always be smelly unless chemically treated. A distillate of 33° to 34° Bé., corresponding in boiling range to the mineral sperm oil of eastern manufacture, was formerly in much demand, under the name "stove oil," for use in domestic stoves and heaters. This oil was usually treated to a sweetish odor and a straw color with strong caustic solution, though the best grade was brought up to a 10 Saybolt color by acid treatment. The general introduction of gas for heating has almost closed this outlet. Heavier distillates, from 28° to 22° Bé., are made in limited quantities for small boilers and water heaters, and for smudging. Such distillates are sold in the raw state, in which they have an offensive odor. Since the market for this distillate is small and not increasing, the fuel distillates as well as the heavy end of the kerosene cut are usually left in the fuel residue, when this is not run down to asphalt and lubricants.

The *lubricants* from asphaltic crudes are handled in the same general manner as on the Gulf Coast, but quite differently from Pennsylvania or Mid-Continent practice. By the time the distillate shows any appreciable viscosity, or when it has reached a gravity of 20° Bé. at the condenser tail, the still bottoms will be down to about

13° gravity and will contain 20 per cent or more of 40 pen. asphalt. It is obviously impossible to remove such a proportion of asphalt by acid treatment or filtration, and so far as the writer knows no feasible method for precipitating this asphalt has yet been proposed. It follows that the lubricants from our high-asphalt crudes are necessarily made from a distillate.

The methods of manufacture are almost as numerous as the refineries making these products. In one instance the cuts for finished oils are made direct from a battery of residuum stills, using steam-cooled dephlegmators, and they are then acid treated, neutralized, washed, and filtered. In another, a straight lubricating cut is made from the residuum stills. This is acid treated, neutralized, washed, and refractionated, the fractions being either steam-reduced or dephlegmated to sweeten, and finally treated again and in some cases filtered. An old method, not now in use, so far as the writer knows, but which had some merit, was to run a whole lubricating cut, acid treat, neutralize, and wash. The treated distillate was then reduced to the viscosity desired for each finished oil, and again acid treated, neutralized, and washed, a separate portion of the treated whole distillate being taken for each grade required.

Regardless of the combination used in distilling and treating to viscosities and colors, there are certain generalities regarding the refining of cold test California lubricants which apply in all cases. In the first place, these crudes are extremely subject to decomposition in the crude still, and care must be taken not only to avoid excessive temperatures and poor circulation, but also not to run to too hard an asphalt. In most cases it is impossible to make a clean lubricating distillate when running below 60 pen. asphalt, though occasional crudes of low sulphur content show greater heat stability. The raw distillate from the crude always contains a material proportion of naphthenic acids, usually 1 per cent and often more. Acid treatment does not remove these bodies, and if left to be removed by the alkali wash which follows such treatment, they are very liable to cause emulsions. Also by reason of their tendency to hydrolize with the water wash, they can never be

removed by a single neutralization, and to obtain a neutral finished oil at least two applications of alkali, with thorough washing after each, are required. It is therefore far preferable to remove these acids by the application of caustic lye prior to acid treatment. On the other hand, if the distillate is not to be redistilled, but is to be treated directly to color, pre-neutralization is often barred because of the darkening which takes place. This darkening is due to oxidation of the distillate, with the production of asphalt, which is left as a still bottom if the distillate is re-run, but otherwise has to be treated out with an excessive consumption of acid.

California lubricants take acid very readily, and may be treated to any desired color. However, as they are also extremely susceptible to oxidation, particularly in the presence of alkali, pale colors are often, or usually, lost in neutralization and the oil takes on a brownish tint and a blue outertone. It is considered good average practice to wash a 300-viscosity oil to a 3 color, N.P.A. scale, and a 600-viscosity oil to a 5.5 to 6 color, though by taking special precautions a 600 oil can be washed down to a 5 color, and oils up to 1,200 viscosity have been treated and washed to a 6/7 color.

Many improved methods of treating have been devised to obviate the long contact of hot oil with alkali, and thus to reduce the loss of color due to oxidation. These include cyclic water washing of acid oil, centrifugal water washing of sour oil prior to neutralization, centrifuging of neutralized and partly washed oils, steaming down of soaps out of contact with air, and the use of demulsifying agents. Some of these have given good results and are in commercial use. Another method which seems to have considerable possibilities is the application of a suitable pulverized clay (one having strong adsorbent properties) direct to the acid oil. Under suitable conditions the acidity may thus be completely removed, and at the same time a decolorizing effect obtained, with considerable economy of acid, oil, and time. Clay alone, however, will not remove any large proportion of naphthenic acids when used in commercial doses.

Filtration to color was once considered to be inapplicable to California lubricants, but experience has shown that this opinion

was an error, based on improperly prepared stocks, and that in fact our oils are decolorized with particular readiness by adsorbents. Where clays and other adsorbent materials are applied to neutralized and water-washed oils it is absolutely essential that these be washed as clean as possible, as soap and salts are adsorbed in preference to coloring matters, and at a very low quantity rate per unit of adsorbent. Most adsorbents, particularly those of high-decolorizing value, also have a tendency to split any soaps which may remain after washing, taking up the alkaline element therefrom and rejecting the acid. Thus perfectly neutral or even alkaline oils may, after treatment with a neutral clay, be found strongly acid.

The practice of percolation through granular filtering clays, which is standard practice elsewhere, is not popular in California. Our local clays are soft and do not hold the granular form so well as the harder clays, and are not efficiently recovered by burning out. During the last few years the practice of so-called contact filtering has been generally adopted in this locality, and seems to have some advantages both here and elsewhere. In this method a finely ground clay, either natural or previously acid treated, is mixed with the oil at a more or less elevated temperature, and after a short contact filtered out in a press.

Asphalt in any grade from a heavy tar to a hard and brittle solid is a necessary by-product in the manufacture of lubricants from the crudes of group 1. The characteristics of this material are too well known to need description.

The yield of asphalt is reduced and its durability increased by the greatest possible reduction in cracking in the still, as by indirect firing, use of liberal proportions of steam, and distillation under a partial vacuum. Direct contact distillation, in which fire gases are forced over or through the oil to supply heat and carry off vapors, produces an asphalt of exceptional quality. A class of asphalts having unusual resistance to temperature changes, and therefore highly desirable for paving and for wall coating, is produced by passing regulated quantities of air through the still during distillation. The result is a strong oxidation which greatly increases the yield of asphalt, but destroys the lubricating cut.

REFINING OF WAXY OILS

The discussion of the manipulation of and the products from group 2 crudes applies with a few exceptions to the waxy oil group. The bulk of the production in group 1 is of heavy oil containing little or no gasoline, whereas the larger part of group 2 production is of light oil giving a large gasoline yield. This difference, however, is entirely incidental in so far as classification is concerned, since group 1 contains crudes which give an excellent gasoline yield, whereas some of the heaviest California oils fall unmistakably into group 2.

Gasoline and distillate.—Because the crudes in this group are, as a rule, richer in sulphur than those of low cold test, and perhaps also because wax is present, they are often excessively tender. For these reasons, the crudes from various fields differ greatly, and it is often impossible, even with the most careful distillation, to make without chemical treatment a stable and neutral gasoline. Instability is often, or usually, manifested by the appearance of a pink coloration after a few hours, this changing gradually to a greenish and finally to a yellowish or brownish tint. This discoloration appears to be due to a trace of cracked sulphur compounds which are acted on by both light and air with the formation of dark-colored bodies. Such gasolines are usually somewhat corrosive, and give a poor dish test.

Chemical treatment may take several forms, not all of which, as a rule, will be applicable to any one specimen. The simplest is the application of doctor solution (sodium plumbate), followed by water washing. In cases where this applies, the use of strong caustic in minute doses will usually give the same results, but only if applied immediately after distillation. Neither of those treatments will remove the discoloration if it has proceeded to the yellow or brownish stage.

Very small doses of sulphuric acid will usually remove these impurities, and in some but not all cases bring the gasoline back to color after it has taken on the yellow tint. After acidification the gasoline is neutralized with soda, and water-washed. The larger companies now put all their gasoline through continuous

treaters as a measure of safety. In operating in this manner the pink color is likely to reappear, with the final separation of a red acid liquid, unless the last trace of acid tar is removed prior to neutralization. A variant of this treatment is to dispense with alkali and water, and to deacidify the acid gasoline with finely ground adsorbent clay. This process is probably a little more expensive, but is extremely dependable and otherwise satisfactory.

In place of acid treatment, clay alone may be used, if it has a sufficiently high adsorbent value. This is advantageous in that it produces with certainty a clean and non-corrosive gasoline. The spent clay, which may be used again at nearly its original value on lubricants, should always be filtered out, as dependence on gravity for its removal is almost certain to lead to trouble sooner or later.

Kerosene of the highest quality may be made from these crudes, but only by methods differing from those in common use. Treatment with 66° acid in the cold gives only an export grade, even on a close-cut stock. As the quantity of kerosene distillate available greatly exceeds the demand, it is desirable to make a very narrow cut, say from 44° to 40° inclusive, which gives an average raw cut of 42° and lies below the boiling points available for blending with casing head. By treatment with 66° acid only a small loss occurs, the distillate is readily brought to a water-white color but the burning properties are poor.

On such a cut, a treatment at about 150° F. with 30 pounds per barrel of 15 per cent oleum produces a heavy tar which, on suitable treatment, gives a high yield (up to 10 per cent of the stock) of the aromatic bodies xylene and cumene. The presence of important proportions of benzone homologues in this class of crudes is thereby proved. A loss of 10 per cent or more in volume occurs, and the kerosene, after rigorous water-washing, neutralization, and redistillation, should have a water-white color, a sweet odor, a gravity of 44.5 to 45° Bé., and highly superior burning qualities. This process is obviously costly, though it is in general use on the Pacific Coast. It is customary to use a much broader cut, though under present market conditions this seems irrational.

The chlorination of kerosene with sodium or calcium hypochlorite is said to give good results for improving the burning quality of this kerosene. Chlorine attacks only the sulphur compounds and does not affect the proportion of aromatics. If chlorination actually produces a free-burning oil from such crude as that from Santa Maria, such a result would be proof positive that the smokiness of our kerosene is due to the small proportion (0.1 to 0.2 per cent) of sulphur rather than to the large proportion of aromatic bodies rich in carbon. If so, the deep cuts effected by fuming acid and by liquid sulphur dioxide are dead loss, except as they incidentally remove the sulphur. In the writer's opinion this remains to be proved.

The Edeleanu process of fractionation in the cold with liquid sulphur dioxide, acts on our kerosenes as it does on those of Borneo and Roumania, that is, it separates the oil into a light and a heavy fraction. The latter is dark and somewhat tarry, whereas the light fraction is highly purified and has excellent burning qualities. These results do not answer the question above, as both sulphur and aromatics pass into the heavy fraction.

A series of very careful oxidations of kerosene with manganates and chromates, followed by a light acid treatment for color, give in some cases complete elimination of the sulphur without change in aromatics, and a marked improvement in burning qualities. The same results are obtained when the stock, after a light acid treatment, is acted on by highly adsorbent clay, though in this case there is also a decided reduction in the aromatics. None of these experiments give strictly first-quality burning tests.

Lubricants.—The information regarding the properties of lubricants from our waxy crudes is highly incomplete, due to the difficulty of dewaxing on a laboratory scale. The wax in these cuts as they come from the crude still is pasty or gelatinous, though it can be changed to the crystalline form by several redistillations. This, however, involves so much cracking that the original properties of the stock are completely destroyed. The uncracked wax will not cold settle, though it appears to be possible to centrifuge it out after dilution.

In a general way it appears that the dewaxed stocks are of better quality, or perhaps they approach more closely to the standard type, than the stocks from our cold test crudes. They are undoubtedly less subject to oxidation and are more cheaply treated than the natural cold test stocks. They probably give finished oils having a better viscosity curve. The products of extremely high viscosity, which are yielded in quantity by the cold test stocks, seem to be absent. In other respects, so far as I know, no distinction can be drawn between the cold test and the waxy stocks, after the wax has been removed from the latter.

Asphalt.—The asphalt from the crudes of group 2 is, in general, of higher ductility than that from cold test crudes. The yield also is relatively much larger from any given gravity of oil.

By maintaining the heaviest members of this group at a moderately high temperature, say 300° F., in the open air, they may be converted almost without loss into hard asphalt, the oxygen adsorbed from the air replacing in part the slight evaporation loss.

The quantity of asphalt available from the manufacture of lubricants alone is materially in excess of present market demands, and such excess quantities are made use of by blending back to fuel oil viscosity with lighter distillates, crudes, or residua.

IMPURITIES IN ASPHALTIC OILS

Impurities are not peculiar to California crudes, though the quantities and manner of combination are to some extent characteristic.

Nitrogen compounds of a basic nature are found in considerable quantity in some of our oils, but the number of determinations made does not justify any generalizations. Determined as free nitrogen, Kern River crude contains up to 0.8 per cent by weight, which, considering the high molecular weight of these compounds, represents a considerable proportion of basic bodies in the crude. These are readily soluble in and extracted by the acid used in finishing.

Acid bodies, apparently both naphthenic acids and phenolic compounds, are found in slight quantity in gasoline and kerosene, and in large proportion in fuel and lubricating cuts. The acids

are not so readily washed out, because of their tendency to hydrolize. The acids cannot be distilled without decomposition, but may be purified by a light acid treatment (which probably attacks the phenolic constituents) followed by treatment with clay. They form resinous, gummy soaps with aluminum and lead, closely resembling the corresponding oleates, and, like these, they are soluble in mineral oil, producing stringy, viscous oils and greases. Such solutions hold up even better than those of aluminum oleate. When the petroleum acids are separated after acid treatment of the stock, they are contaminated with salts of alkyl-sulphuric and of sulphonic acids, and have then somewhat different properties.

Sulphur is present in most of our crudes in quantity, and in an objectionable form. It is impossible to state just what these compounds may be, though it is probable that they are sulphur alcohols of high molecular weight. At any rate, these compounds are not excessively subject to heat decomposition, and when the crude is carefully distilled they come out unchanged in the heavy fuel and lubricating distillates. In this form they are only partly soluble in either acids or alkalis, though they may be completely removed by a rigorous acid treatment. When overheated, the sulphur compounds partly decompose, the sulphur taking up hydrogen and coming off as hydrogen sulphide, thus forming asphalt in the residue. Unsaturated hydrocarbons are also produced in both distillate and residue. Desulphurization is promoted by this cracking, but acid consumption is increased and stability decreased thereby. The sulphur in volatile distillates is, as a rule, but little affected by sodium plumbate treatment. It may, however, be removed by other methods above described.

DYNAMICS OF OIL-FIELD STRUCTURE IN SOUTHERN CALIFORNIA[1]

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In working in the flat alluvium-covered basins of southern California, which have in recent years been such a prolific source of oil, the geologist is greatly handicapped by the almost total absence of indicative exposures, and must depend for his data as to the location of new oil fields on physiography, correlation of well logs, and other more or less uncertain criteria.

There has recently been considerable speculation as to the probable genesis of the various structures and the nature of the forces which have formed them. A thorough understanding of this subject would be of great help in the location of otherwise geologically obscure structures, and would obviate the drilling of prospect wells in areas where favorable structure is more or less of a mechanical impossibility.

As a result of exploration work carried on by the writers during the last two years largely in the Los Angeles Basin, certain theories along these lines have been developed which are presented in this paper together with an example of their application to a particular structural problem.

License to theorize is taken on the grounds that, in an area like the Los Angeles Basin where there is so little positive evidence upon which to base predictions as to the structure in the oil horizons, anything which will increase the percentage of correct guesses is of value. In order that the subsequent reasoning may be more readily followed, a résumé of the general geological situation in the Los Angeles Basin is included here.

The Los Angeles Basin covers an area of approximately 1,000 square miles, and may be said to be bounded on the south and

[1] Read before the Association, Houston meeting, March 27, 1924. Manuscript received by the Editor, April 30, 1924.

west by the Pacific Ocean and on the north and east by the Santa Monica, San Gabriel, and Santa Ana Mountains. It is essentially a portion of the geologic province of the California Coast ranges, and has been an area of subsidence during most of Tertiary time. Its low, flat topography is broken at intervals by a series of northwesterly trending ridges of varying degrees of relief, and it is along these ridges that most of the oil development has so far occurred.

While there is some question regarding the age of the oil-producing horizons, they are generally accepted as Lower Pliocene, and the oil is generally believed to have originated in the underlying Miocene (?) diatomaceous shales. The region is characterized by the great thickness of the producing horizons, over 3,000 feet of oil zone having been developed at Signal Hill.

In the flatter portions of the basin the 2,000–3,000 feet of Pliocene marine shales and sands which overlie the oil zones are overlain by some 800–1,200 feet of Pleistocene shales, sands, and gravels—partly marine and partly fluviatile in origin. These are in turn overlain in portions of the basin by the recent alluvial cones of the Los Angeles, San Gabriel, and Santa Ana rivers.

Within the basin fifteen different fields have been developed. Of these the Olinda, Puente, and Whittier fields are accumulations along faulted anticlines in the more mountainous and sharply folded Puente Hills (Fig. 1). The accumulation in the old Los Angeles field appears to be due to the trapping of oil in an unconformity along a sharply tilted monocline. The Salt Lake and Torrance fields are apparently both accumulations on plunging anticlines, trapped by unconformities or faulting. The remaining fields of Richfield, East Coyote, West Coyote, Santa Fe Springs, Montebello, Signal Hill, Dominguez Hill, and probably Huntington Beach are all true anticlinal domes with closures varying between 300 and 1,000 feet and productive areas varying from 700 to 2,000 acres each.

In the fields of the Puente Hills, in the Coyote Hills, in the Montebello field, and at Signal Hill relatively older beds came through the mantle of the late Pleistocene and Recent sediments and exposures, showing structure, are available. In the remainder of the oil district the surface of the Pleistocene deposits has been

slightly bulged by post-Pleistocene growth of the underlying anticlines into low hills which correspond more or less in position and shape with the more pronounced anticlines in the underlying sediments.

FIG. 1

The areas suggested as favorable on topographic evidence are rapidly being developed, however, and other criteria are necessary to predict with any degree of certainty the location of new fields in the areas where the topographic expression of the Pleistocene surface has been so modified by erosion as to defy interpretation. The

same is true of areas where the blanket of Recent river alluvium covers up all possible topographic evidence. It is in these areas that an understanding of the nature of the formative structural mechanism is of the greatest value.

There are several major theories concerning the nature of this mechanism which are backed up by such a mass of indicative evidence as to appear highly probable. The first of these is that underlying the 10,000 or 15,000 feet of sediments in the Los Angeles Basin is a more or less rigid basement in which movement manifests itself in shearing rather than in folding, and that movements along shear zones in this buried basement have produced folding, sagging, or faulting in the overlying sediments according to the direction and amount of this movement. These shear zones appear to divide the basement into blocks and strips which have moved and are probably still moving with respect to one another, and along the edges of which have been formed a large number of folds.

The second theory with which we must deal concerns the direction of pressure and the resultant movement of the basement blocks. A map of the Los Angeles Basin shows immediately that the oil fields are for the most part arranged along northwest-southeast trending lines, and that in several instances fields in the same northwest-southeast line lie *en echelon* to one another and on separate anticlines rather than along the same anticline. If one takes two pieces of cardboard, places them edge to edge and pastes a piece of tissue paper across the crack between them, he has a crude model of the condition of blocks and overlying sediments described above. Now if one aligns this crack between the cardboards in a northwesterly direction, and moves the southwesterly block to the northwest with respect to the northeasterly one, echelon folds will be formed in the paper along the crack in similar position to the echelon folds of the Los Angeles Basin. This suggests that the motion on the northwesterly trending faults of the basin is probably similar to that of the cardboards, or largely lateral and to the northwest on the ocean side. The existence of lateral motion of this type on the northwesterly trending faults throughout the California Coast ranges is becoming more and more generally accepted, and is supported by a large amount of evidence. Con-

siderable data have been collected along these lines by Lawson, Vickery, and others.[1] In the earthquake of 1906 the western side of the San Andreas fault moved from 8 to 20 feet to the northwest with respect to the eastern side. This was measured by means of dislocated fences, roads, and so forth. Total offsets of from 12 to 15 miles along several of these faults are pretty thoroughly proved in a number of places.

With regard to the force which is responsible for the lateral movement on these faults, all the evidence tends to show that there is a northward creep of the mass beneath the ocean with respect to the mainland mass or shield of the Sierras, and that the region of the coast ranges represents the shear zone between these two great masses. The mass beneath the ocean, moving northward, presses against the northwesterly trending coast line and slides northwest along it, exerting, of course, great northeasterly pressure against it which is responsible for the parallel northwesterly trending folds in the more sharply folded portions of the coast ranges.

Considering now the action of this pressure along a single line of shear, it may be noted, as shown in Figure 1, that the pressure will be divided into two components, one of which will produce shearing in a northwesterly direction and the other of which will produce folding approximately parallel to this shearing. This folding will never be quite parallel to the shearing theoretically because of the component of friction on the shear line. Now if the shearing is complete only in the buried basement and does not extend up into the overlying sediments, this pressure from the south will not be divided into two components in the sediments. Instead of folds approximately parallel to the shear line, which would occur were the shearing complete, folds will be formed in an east-west direction, and on an angle to the shear line. These folds may be rotated into a northwesterly direction by subsequent movement along the fault, but they will remain essentially offset with respect to one another.

This is particularly interesting because it explains the fact that while the folds of Santa Fe Springs, West Coyote, and Dominguez

[1] A. C. Lawson and associates, "Report of the State Earthquake Investigation Commission," *Pub. Carnegie Institution of Washington* (1908–10); A. C. Lawson, "The Mobility of the Coast Ranges of California," *Univ. Cal. Pub., Dept. Geol.*, Vol. 12, No. 7; F. P. Vickery, an unpublished work on the structure of the Livermore area, California.

Hill appear to be of the offset type and on an angle with their parent shear lines, the folds of the Olinda and Whittier fields along the south side of the Puente Hills fault, and those of Huntington Beach and Signal Hill along the southern end of the Inglewood fault, do not appear to be offset to one another but lie practically end to end and nearly parallel to their respective fault lines. The obvious deduction is that in these latter areas the shearing is complete in the beds above the basement as far up at least as the competent beds which govern the direction and shape of the folds, and that the pressure from the south has been divided into the two components described above.

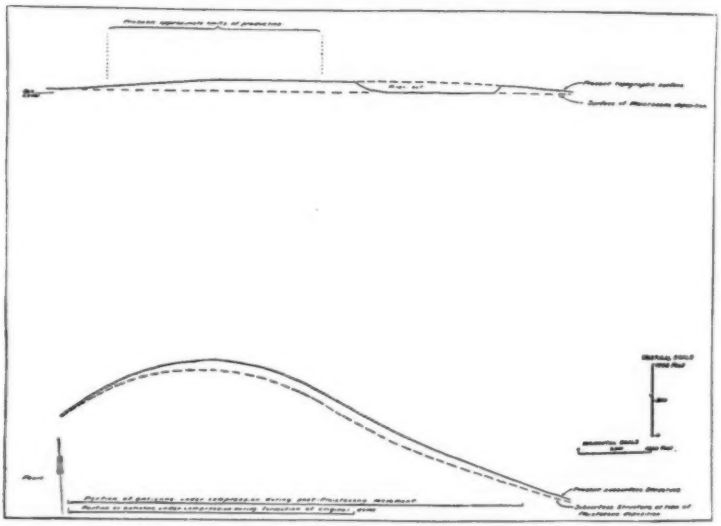
The northwesterly trending shear lines should not be confused with the numerous transverse faults which trend in a general east-west direction across the area. The dominant motion on these faults is vertical, as shown by their abrupt scarps, and there is no evidence to indicate any large amount of lateral motion on them.

It will be noticed that the transverse faults along the south side of the Santa Monica and San Gabriel Mountains cut off several of the northwesterly trending shear lines. Obviously if there has been any lateral motion on these shear lines, it must have been taken up somewhere against these barriers for the shears do not go through them. And this motion has been taken up by east-west folding in the northern corners of the various blocks. This is particularly apparent in the anticlines of the San José Hills west of the northern end of the Elsinore fault. Likewise, the Montebello fold appears to be due to taking up of the lateral motion on the Puente fault against the Santa Monica Mountains.

An application of these theories to a practical problem is of interest. Dominguez Hill in the Los Angeles Basin, where the recently discovered Compton field is now being developed, is an echelon fold along the northwestern side of the Inglewood fault or shear line. It lies some 4 miles northwest of the Signal Hill fold with which it is *en echelon*. The topographic expression of the hill is that of an almost perfect anticlinal dome (Fig. 2). The river cut across its eastern end, a slight shore-line groove around its southern and western slopes, and a few clean stream cuts, due to drainage off the Hill itself, have only slightly marked the

smooth, bulged surface of the late Pleistocene sediments. As the field is developed it is becoming increasingly apparent that the surface topography does not correspond in shape with the subsurface structure, but that the subsurface structure appears to lie in the extreme western end of the hill itself.

A possible explanation for the apparently misleading topographic expression of Dominguez Hill presents itself when one considers



IDEAL DIAGRAMATIC SECTION
ALONG AXIS OF
DOMINGUEZ HILL

FIG. 2

its probable method of formation. The forces which are responsible for the structure of Dominguez Hill have undoubtedly been at work since the beginning of Pliocene time, and appear to have been in more or less continuous action ever since. It is probable that the western end of the Dominguez Hill anticline, being adjacent to the Inglewood fault, was formed first, and that as the dome at this end became complete the folding progressed eastward along the anticline. In other words, the first stage in the formation of the structure undoubtedly consisted of the growth of the dome at the

western end while the later stage consisted of a comparatively slight accentuation of the whole anticline from the apex east. The gentle bulge of the late Pleistocene sediments which makes up the present topographic expression is of course due to this later and relatively insignificant stage in the development of the structure, and is therefore undoubtedly considerably flatter from the apex east than the subsurface structure. This explains the lack of success of the wells drilled along the eastern end of the hill on relatively high ground in that the structure in the oil horizons probably plunges much more sharply from the apex east than the topography appears to indicate.

BURBANK FIELD, OSAGE COUNTY, OKLAHOMA

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The purpose of this paper is to direct attention to: (1) the importance of the study of sand conditions of any field and the effect of such conditions on the concentration and production of oil, and (2) the probability that rapid development of a field with subsequent open flow from the wells where the producing sand is close-grained produces a much larger ultimate production.

GENERAL GEOLOGY

The geology of the Burbank field has been so well covered in another publication[1] that time will not be taken here to go into this subject in detail.

Osage County is in the northeastern part of Oklahoma. All of the county is underlain by rocks of Pennsylvanian age, which are covered in the northwestern corner by Permian beds. The Pennsylvanian series is composed of interstratified limestone, sandstone, and shale with the sandstone and shale predominating. The general dip of the strata is about 30 feet to the mile a little north of west. The most important oil-bearing horizon of the Pennsylvanian in the county is the Bartlesville sand, which is near the base of the series. It varies in thickness from 30 to 100 feet. In eastern Osage County and Washington County this sand is fairly coarse, porous, and siliceous, but to the west it becomes finer-grained and more calcareous until, on reaching a line running in a northeast and southwest direction almost through the center of the county, it thins and disappears. This led to a lack of faith upon the part of oil men and geologists as to oil possibilities in the northwestern portion of Osage County. It had been known for some time that large structures were located there, but as some of these had been

[1] *U. S. Geol. Survey Bull. 686.*

drilled with unsatisfactory results, no one was interested in that vicinity until the Carter Oil Company developed production in the NE. of Sec. 9, T. 26 N., R. 6 E., in September, 1920, and the Marland Oil Company in the S.E. of Sec. 36, T. 27 N., R. 5 E., in May, 1920. From that time on, at each successive Osage sale, prices for acreage in this field have increased until in September, 1922, $1,600,000, or $10,000 per acre, was paid for 160 acres in the southeast quarter of Sec. 24, T. 27 N., R. 5 E., and many quarter-sections have sold for over $1,000,000 each.

STRUCTURAL CONDITIONS

Figure 1 shows structural conditions apparent on the surface, using the Stonebraker limestone as a datum. Figure 2, a structure map using the top of the producing horizon as a datum, demonstrates the conformity of the surface and subsurface strata, although, as usual in Osage County, the reversal on the east side and dips on the west side of the folds are greater on the producing sand than at the surface. These structure maps show the highest point of the Burbank fold in Sec. 9, T. 26 N., R. 6 E., with a reversal or dips to the east and south of about 30 feet in each direction. On the western flank of the fold where Townships 26 and 27 and Ranges 5 and 6 meet, is a lesser dome with about 20 feet reversal. A study of Figure 2 will show several other small domes farther north and west. The structure, then, might be classed as a plunging anticline with the major axis running northwest and southeast and its highest point near its southeastern extremity.

PRODUCING SAND

While the Burbank sand does not seem to be connected with the Bartlesville sand, it appears to occur in the same stratigraphic position. As far as we have been able to ascertain, the sand of this field is a delta deposit. A small amount of this sand is present at the southern end of the Mervine field, 10 miles west, in Kay County, and it appears to be continuous with the Burbank sand. There are a few other small local sand bodies in the western Osage which correlate with the Burbank sand but do not seem to be connected with it. Therefore, while the Bartlesville sand was apparently deposited

from a land mass to the east, this sand has probably been deposited in the same sea and at the same time, but was derived from a land mass to the west. While there may be several such deposits, the sand in the Burbank field is probably the largest and most productive of these.

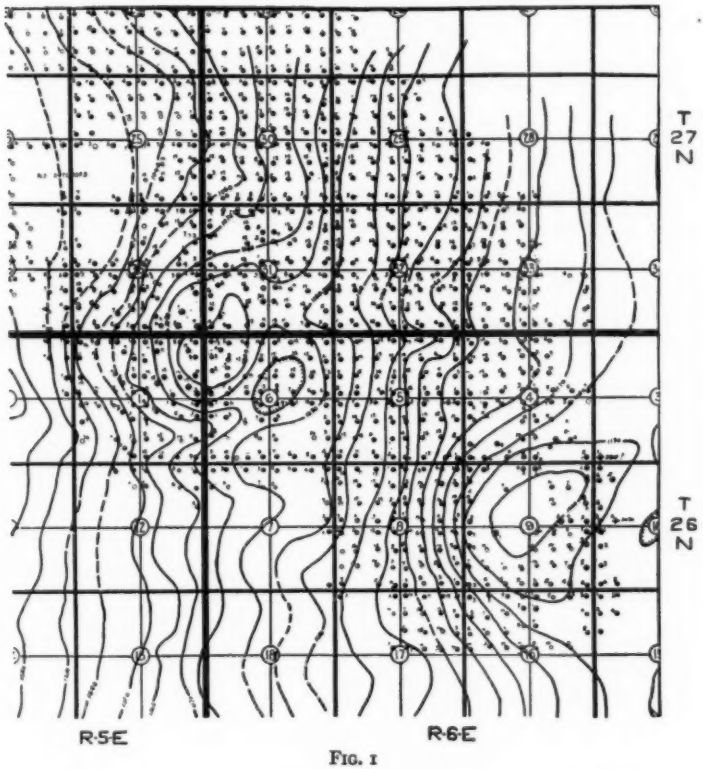

FIG. 1

The thickness of the producing horizon varies from 50 feet to 80 feet. It is a fine-grained, calcareous sand interstratified, to a small extent, with thin beds of blue or brown shale. It is probable that this whole thickness is not productive. Most wells show increased production at several different points in drilling through the sand.

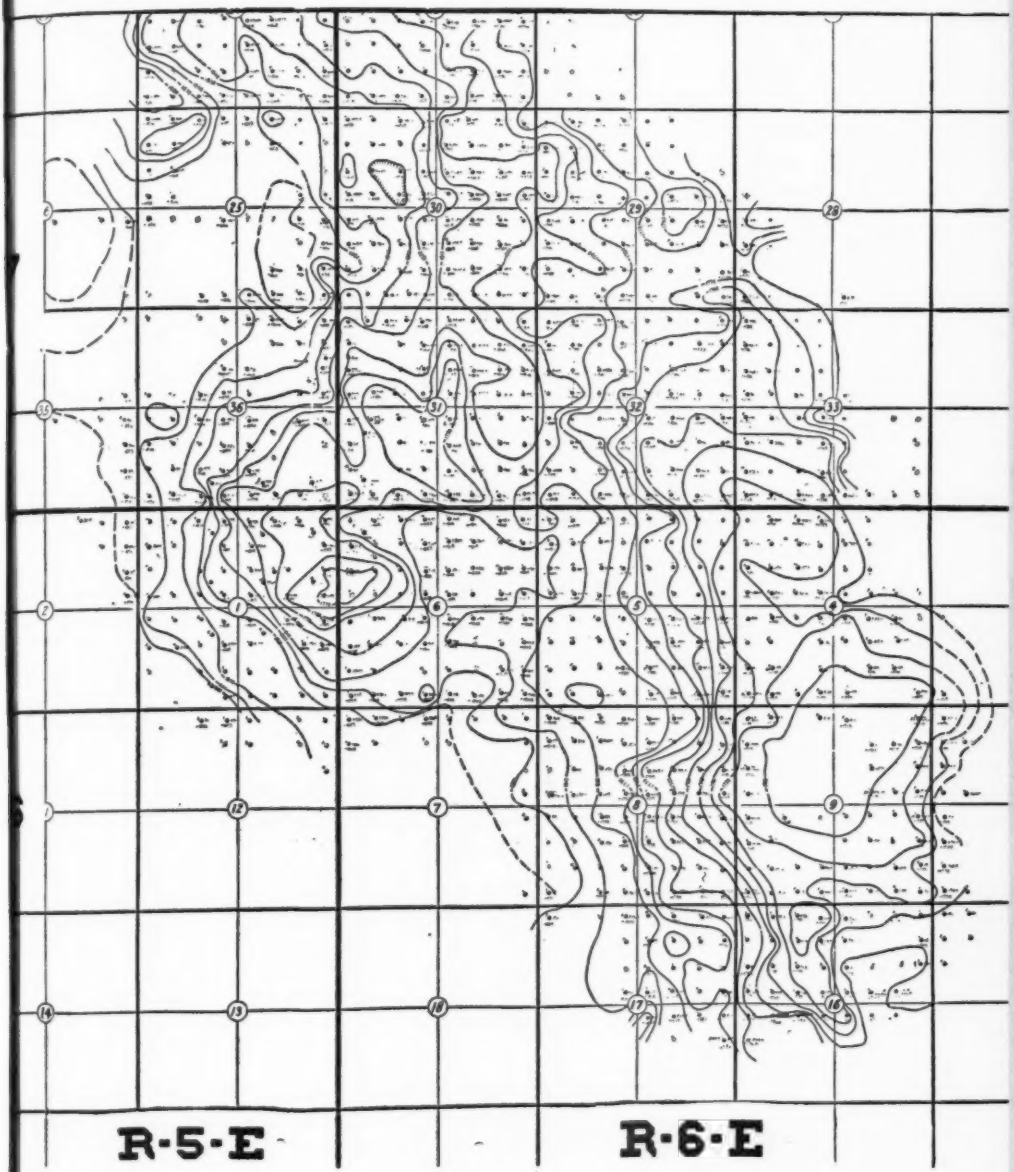

FIG. 2

From the best information obtainable it seems probable that from 25 to 40 feet of this sand is productive, this thickness being divided into three or four zones. Producing wells have an initial yield of 50 to 8,000 barrels per day, accompanied by considerable gas. In many of the wells a pure gas sand, 10 to 30 feet in thickness, is found on top of the oil sand. In some wells a 3-foot break of blue shale separates this gas sand from the oil. Production, then, in this field seems to be confined on the north and east sides by a gradation of the sand to an impervious shale, while on the south and west sides it is confined by salt water as the normal dip is continued to the west.

PRODUCTION

The production of the Burbank field to December 31, 1923, was 61,923,485 barrels from 1,110 wells on 120 quarter-sections.

TABLE I

Section	Date First Well Drilled In	Total Production to Dec. 31, 1923	No. Wells Completed to Dec. 31, 1923	Production per Acre	Length of Time Producing	Subsea Elevation Top of Sand
		Bbl.		Bbl.	Months	
1. 9-26-6	Sept., 1920	2,234,698	44	3,500	40	−1,710′
2. NE. 1-26-5, NW. 6-26-6, SW. 31-27-6, SE. 36-27-5	Dec., 1920	2,261,320	63	3,500	37	−1,780′
3. 30-27-6	Aug., 1921	2,996,053	64	4,700	28	−1,800′—1,840′
4. S.½ 24-27-5	Oct., 1922	3,591,482	32	11,500	15	−1,820′—1,880′
5. NW.¼ 24-27-5	Apr., 1923	2,075,320	13	13,000	8	−1,820′—1,880′

To bring out the fact that some agency other than structural conditions is responsible for the relative concentration of oil in the different parts of this field, five different groups of leases have been selected: (1) located on the highest point of the structure; (2) located on the second highest point of the structure; (3) one of the most centrally located and best producing sections in this part of the field; (4) and (5) the most productive portions of the field to date, 170 feet structurally below and 3 miles from the highest point.

A pertinent question, then, is: Why is the best production located 3 miles from the top of the structure and well down toward

its lower end? It seems probable that the fine-grained character of the sand is largely responsible for this.

First development took place on the two highest parts of the structure, gradually moving north and west. Lessening of gas pressure on one lease has had very little influence on the gas pressure of a lease a half-mile away, and as the territory was developed farther north, wells a half-mile from older production came in with the same gas pressure, as would have been expected had no drainage taken place. It is also true that the higher portions of the anticline contain the largest proportion of gas, although the oil seems to be intimately mixed with sufficient gas at high pressure, even at the lowest points yet developed, to cause the wells to flow violently. Therefore, it would seem that gas, oil, and salt water accumulated in their respective places according to laws postulated in connection with the anticlinal theory, but, because of the fine-grained nature of the sand, did not migrate much from one lease to another after development started, but were largely produced from their original positions. As the sand on the lower portions of the fold had the largest oil content, these leases are most productive. When studying a new field it should, therefore, be kept in mind that sand conditions are often more important than structural conditions in locating the most productive portion of the pool. This is very important where prices are as high as has become so frequently the case in fields developed within the last few years.

Another cause which has helped to make the northwestern portion of the Burbank field so much more productive than the southern portion has been the rapidity with which the quarter-sections have been developed. In the southern portion, some quarter-sections are not yet fully developed, and many had an interval of fifteen months between the finishing of the first and the last wells. The northwest quarter of Sec. 24, T. 27 N., R. 5 E., owned by the Gypsy Oil Company, is the most productive lease so far developed. Thirteen wells were drilled on this tract before the shut-down agreement in this field took effect. There was less than two months between the finishing of the first and last of these wells which came in at from 1,600 to 3,600 barrels daily. This was the most rapid development in the field. The three remaining

wells were brought in eight months later, producing only 60 to 900 barrels daily. Quarter-sections on either side of this one which were developed more slowly have not produced much more than half as much oil. The south half of Sec. 24, T. 27 N., R. 4 E. is the next most productive portion of the field and was also the next most rapid in development. Four months elapsed between the completion of the first and last wells. It was quite noticeable that gas pressure in many of these wells lessened more rapidly than oil production. The quick development allowed the greatest advantage to be taken of this gas pressure before it was dissipated, with a consequent large production of oil. This seems to bring out clearly the advisability of rapid development of an oil field where the producing sand is compact and fine-grained.

To bring this out more clearly, another example is given. The drilling of wells in 52 locations in this field was delayed over 90 days behind other wells finished on the same leases. The average production of these other wells was 300 barrels daily each. Therefore, if these 52 wells had been drilled in we might have expected them to produce 15,600 barrels per day in all. From the general decline in this vicinity it is figured that the production of these wells will be less than 200 barrels each at the end of the 90-day period. This, then, shows a loss of 1,115,000 barrels of production, caused by delay in drilling these wells in, which, at $2.00 per barrel, means a $2,230,000 loss. While granting that the decline in production of these leases as a whole might have been slightly more had all of these wells been drilled in without delay, yet the history of the field has shown that the decline in production where all of the wells on a lease are completed is by no means sufficient to make up the loss of flush production obtained when the gas pressure is in its original high state. In fact, settled wells in this field, as a whole, obey the law of equal decline from the same-sized wells, regardless of age. High ultimate production, then, can only be obtained where flush production under high gas pressure is large.

Gester, Gester, and Wagy, in their article entitled "More Oil through Closer-Spaced Wells," state in part:

> Gas is one of the principal motive forces which propels or carries the oil through the sands into a well and causes the well to flow or gush. Moreover,

gas is one of the important factors governing the accumulation or concentration of the oil into commercially productive fields. At depths found in the oil fields the gas is frequently under heavy pressure. When this pressure is released by the drilling of a well the gas moves toward the outlet, carrying oil with it. Because of its much greater mobility, the gas moves more rapidly than the oil and there is an opportunity, as the pressure is released, for some of the gas to become dissociated from the oil and for the oil to lag behind the gas in its movement toward the well.

This is exactly what seems to happen in the Burbank field and after the initial gas pressure has been largely dissipated, it is questionable if any but a very small area around each well can be drained of a reasonable proportion of the original oil content.

This can be reasoned out in a different manner: It takes a certain amount of pressure to drive oil a certain distance through the sand to a well. The finer-grained the sand and the greater viscosity possessed by the oil, the more pressure is required to drive the oil from the sand to the well. In Burbank the original pressure in many portions of the field was 800 pounds to the square inch. It is conceivable, therefore, that with the drilling of the wells there, at one well to 10 acres, it takes 800 pounds to drive some of the oil from portions between these wells to the well. As stated above, however, gas travels much more easily through the sand than oil and, therefore, less pressure is required to drive it to the well. This allows one or two wells on a quarter-section to dissipate the pressure on a whole lease within a few months so that wells completed later find a gas pressure of only 100 to 200 pounds per square inch. From the smaller production of these wells it would seem that this pressure is only sufficient to drive to the well the oil that is in close proximity, leaving a large proportion of the original content in place between the wells. Therefore, as shown in the foregoing production table, production from wells where the development has been slow and the gas pressure dissipated is very much less than where the lease is developed rapidly and the original gas pressure utilized to bring all the oil possible to the well. This statement is also agreed to by Cutler and Clute in their article on "Recoveries in Oklahoma Fields," and by Swigert and Schwarzenbek in their report on the "Hewitt Field of Oklahoma," where in two different instances from 53 to 73 per cent of the ultimate production was lost on account of

delayed drilling. This, therefore, is not a new subject, but it is one of the most important ones facing the oil engineer or geologist today. At present we seem to be faced with an ever increasing consumption which must be supplied, and if petroleum engineers or geologists can increase production from new fields by 25 to 50 per cent of the flush production, with practically no additional cost to the producer, they will be doing a very great service, not only to their own companies but to the consuming public as well.

From the many fields which the writer has examined, it appears that it should be possible to work out definite data in this connection, the factors to be considered being gas pressure, viscosity of the oil, and the porosity and nature of the sand. Where the sand is very porous and the oil is mobile—enough so that the oil and gas would move with almost equal ease through the sand to the well—dissipation of the gas pressure without a corresponding production of oil would not take place. But where the sand is fine and close-grained and where the oil is heavy and viscous, the gas would travel through the sand much more rapidly than the oil and be uselessly dissipated. It, therefore, should be possible to ascertain what might be called the coefficient of resistance of any sand. By taking cores of the sand from several holes in any field, the oil content, porosity, composition, and other characteristics of the sand could be determined. These results, coupled with the viscosity of the oil and the rate of decline of gas pressure, should, with other refinements developed, give a scientific method of figuring out the most economic and profitable manner in which to develop new oil fields.

The writer suggests that such a movement be started by all members of this Association who are interested and who have the facilities to prosecute the investigation. The successful conclusion of such a course would advance this Association another big step in the esteem and confidence it has won with practical oil men and executives.

THE GRAHAM FIELD, OKLAHOMA[1]

C. W. TOMLINSON AND WILLIS STORM
Ardmore, Oklahoma

LOCATION AND HISTORY

Location.—The Graham field lies in the northwestern portion of Carter County, Oklahoma. The present developed area of the field extends from Sec. 23, T. 2 S., R. 3 W., southeastward to Sec. 5, T. 3 S., R. 2 W., in a strip 4 miles long and from $\frac{1}{2}$ to $\frac{7}{8}$ mile wide (Fig. 1). It lies under the Permian red beds, whose eastern edge is but 5 or 6 miles northeast of this field, skirting the western extremity of the Arbuckle Mountain area. The southeastern end of the field is 28 miles from Ardmore by hard-surface roads, and 10 miles from Healdton, which is the nearest railroad point.

History of development.—The first drilling in this vicinity was undertaken in 1917 by the Kirk Oil Company, under the management of Dr. J. E. Bristow. His selection of this area for a test was based in part upon the occurrence of certain small asphalt deposits, and in part on his interpretation of local structure. As the surface rocks give practically no suggestion of the structure in the unconformably underlying Pennsylvanian, however, the discovery of the field must be attributed chiefly to chance and nervy wildcatting.

In the first well drilled, heavy oil was encountered in a sand of the red beds at a depth of about 250 feet capable of yielding about three or four barrels of oil per day. This well was completed at that depth, and three or four others were drilled to the same sand. These very shallow wells afforded a supply of fuel for drilling a deeper well, which was carried in 1918 to a depth of 1,490 feet, where a flow of gas was encountered estimated at 25,000,000 cubic feet, with a rock pressure of about 600 pounds per square inch. All of this early testing was done near the middle of the north half of Sec. 31, T. 2 S., R. 2 W. The gas well just mentioned, which

[1] Read before the Association, Houston meeting, March 29, 1924. Manuscript received by the Editor, April 28, 1924.

was later deepened for oil production, is now known as well No. 1 of the Graham Mineral Trust and the Kirk Oil Company on the James F. Bennett farm.

A quarter of a mile southeast of the Kirk gasser another well was drilled in 1918 to the Kirk gas sand at about 1,500 feet, by C. R.

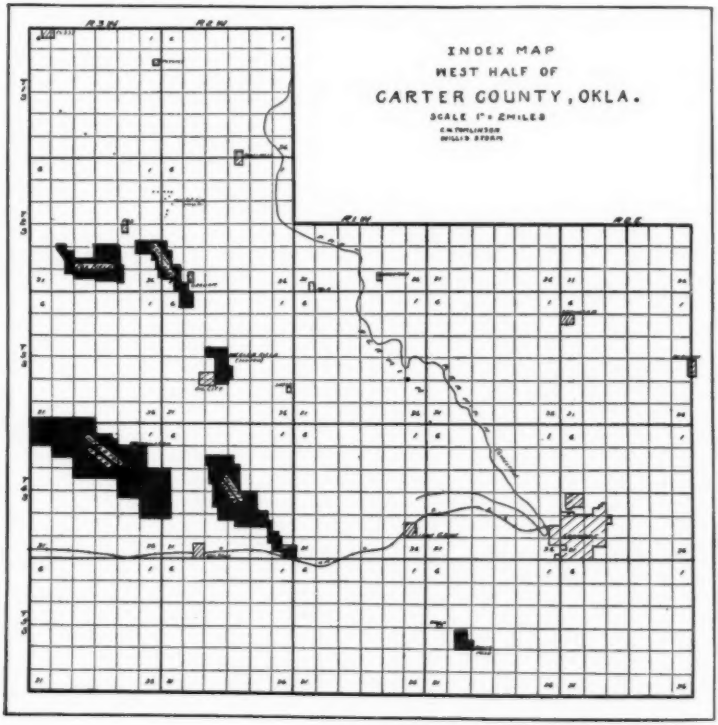

FIG. 1

Smith and the Healdton Petroleum Company, a concern under the direction of Roy M. Johnson. A west offset to this well, drilled by the same operators, found salt water in the Kirk sand, which was encountered at 1,730 feet. This offset was carried deeper in 1919 and obtained an initial production of 100 barrels of oil in broken sand, now known as the Johnson sand, reached at 2,282 feet.

In 1919 and 1920, a number of wells were drilled south and southwest of the Kirk tests, and a number of them found gas at a depth of 900 to 1,000 feet, in sand near the base of the red beds. The area of this shallow gas production lay parallel to, but southwest of, the southern half of the field as at present developed in the Pennsylvanian sands. Few, if any, of these wells ever paid a profit, although a market was found for the gas, and some of it was still in use for drilling purposes as late as 1923.

In 1919 the Kirk Oil Company drilled a dry hole in the NW. quarter of Sec. 32, T. 2 S., R. 2 W., ½ mile east of their Bennett gas well. This, and the failure of the shallower gas wells to yield commercial returns, caused a lagging of interest in the field.

In 1921 two small oil wells near the older Kirk wells were completed in the Atlantic sand, which is stratigraphically about 200 feet below the Johnson sand, in which they had encountered only gas showings; and the Cottonbelt Petroleum Company completed a 30-million-foot gas well in the Johnson sand in the south edge of Sec. 30, T. 2 S., R. 2 W.

In the same year J. B. Schermerhorn and F. W. Merrick, operators in the Healdton field, organized the Graham Mineral Trust and undertook additional drilling for the Kirk Oil Company in consideration of a one-half interest in a part of the Kirk holdings. On April 2, 1922, in deepening the Kirk Oil Company's No. 1 gas well, they completed an oil well with initial production of 226 barrels from the Bennett sand, found at 2,640 feet, 650 feet below the stratigraphic level of the Johnson sand.

From that date, development gradually accelerated except for a halt during the proration of oil runs in 1923. However, the development of this field has been very slow throughout, due largely to the absence of surface guides to extension of the field, to the great variation in depth to pay sands, and to the relatively small average production of its oil wells. Until June, 1923, no well had showed an initial production as great as 500 barrels per day, although several more recently completed wells have exceeded 1,000 barrels initial production.

The total daily production of the field is now standing fairly steady in the neighborhood of 14,000 barrels, with gas sales of

approximately 20,000,000 cubic feet daily. This field has been the chief reliance this winter of the cities of Dallas, Fort Worth, and Ardmore for their natural gas supply. The total oil production of the field from its discovery to December 31, 1923, was somewhat over 1,000,000 barrels.

STRUCTURE

The Graham field is a highly orthodox anticlinal pool. It is unusual for the Mid-Continent field, in the steepness of its dips, which are greater than those of any other producing area of the field up to this time, with the exception of the small Brock or Amerada pool in the same county. Dips in the producing area of the Hewitt field exceeded traditional Mid-Continent limits, but attain a maximum of less than 15°, whereas Graham dips run up to 30°.

The surface red beds at Graham vary from 800 to possibly 1,200 feet in thickness (Fig. 2). They dip gently northeastward across the producing area of the field from an anticlinal axis about 1 mile southwest of the producing area. Slight terracing is present within the field, and a 10-foot closure is reported in a small area in Sec. 25, T. 2 S., R. 3 W., but the controlling structure of the red beds is a fairly steady northeastward dip averaging about 1°. A short distance northeast of the field is a synclinal axis in the red beds, from which the strata rise northeastward toward the Arbuckle Mountains.

Contrasting sharply with the gentle dips and absence of conspicuous folding in the red beds, the underlying Pennsylvanian rocks dip steeply northeast and southwest from a strong anticlinal axis (Fig. 3), and are abruptly truncated by the transgressing red beds. These Pennsylvanian beds are believed to belong to the Glenn formation. The anticlinal axis in the Glenn is roughly parallel to, but about 1½ miles northeast of, the anticlinal axis in the red beds above mentioned. Dips in the Pennsylvanian on the southwest flank of the Graham anticline range from 8° to 25°, with an average of 22°. On the northeast flank they range from 16° to 30°, with an average of 28°. In the southern part of the field these opposing dips converge into a sharp ridge, but farther to the northwest there is a more broadly arched axial area. It will be noted that the northeast flank of the field is somewhat steeper than the southwest flank, a

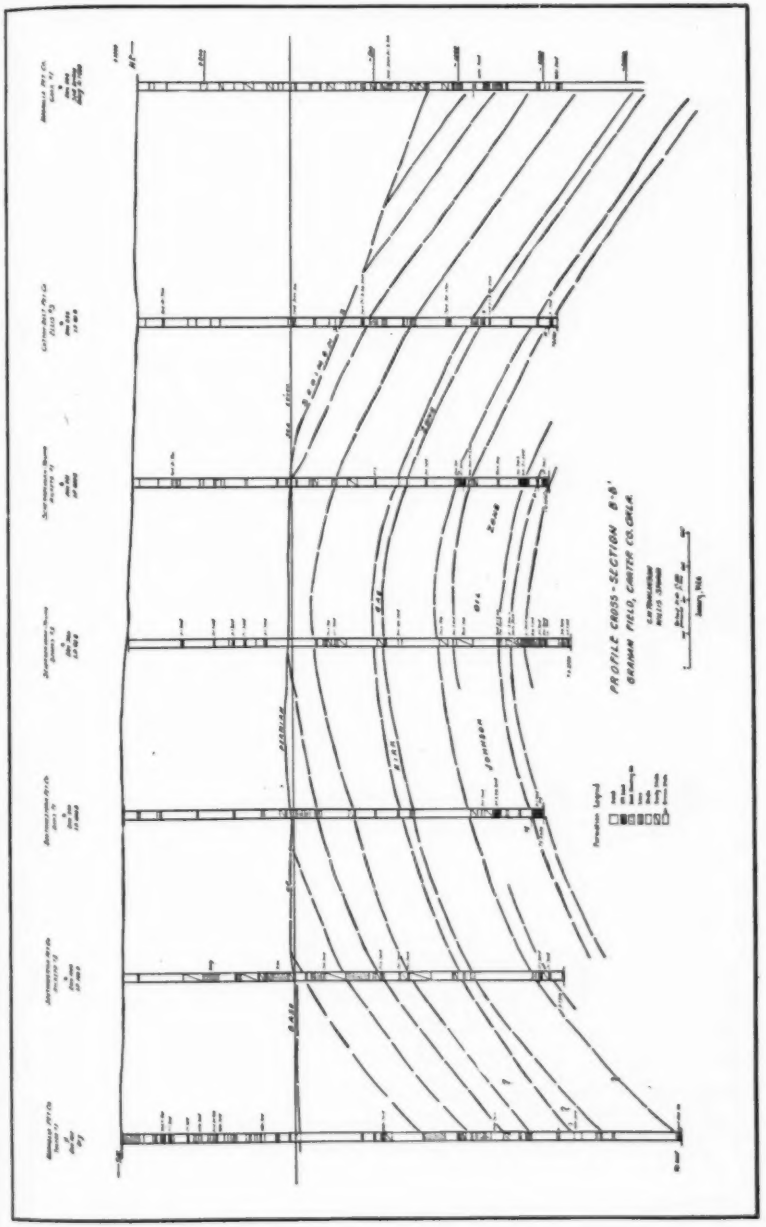

FIG. 2

feature exhibited by several other folds in the Pennsylvanian of Carter County.

In at least one of the producing sands of the field production extends down the flank of the fold to a level more than 1,000 feet

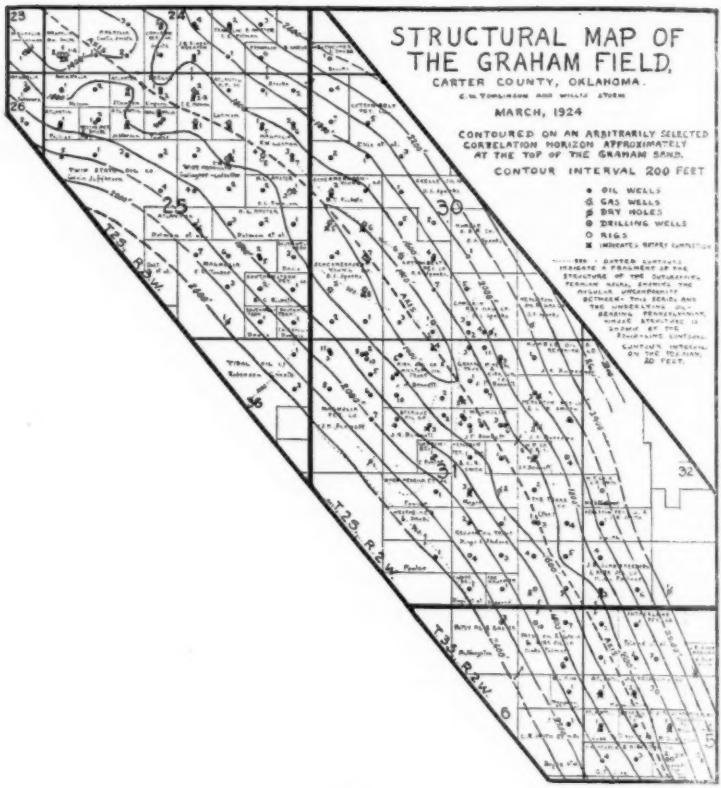

FIG. 3

below the crest (Fig. 4). The logs of certain dry holes demonstrate that the northeastward dip continues at about the same angle for at least another 1,000 feet. A hole in Sec. 29, T. 2 S., R. 2 W., 3,000 feet deep and $\frac{3}{8}$ mile northeast of production, although it penetrated

about 2,000 feet of Pennsylvanian rocks, had not yet reached the top of the Pennsylvanian section which is encountered in wells near the axis of the field. It is evident that a very deep syncline exists between this field and the Arbuckle Mountains (Fig. 5). In the north-

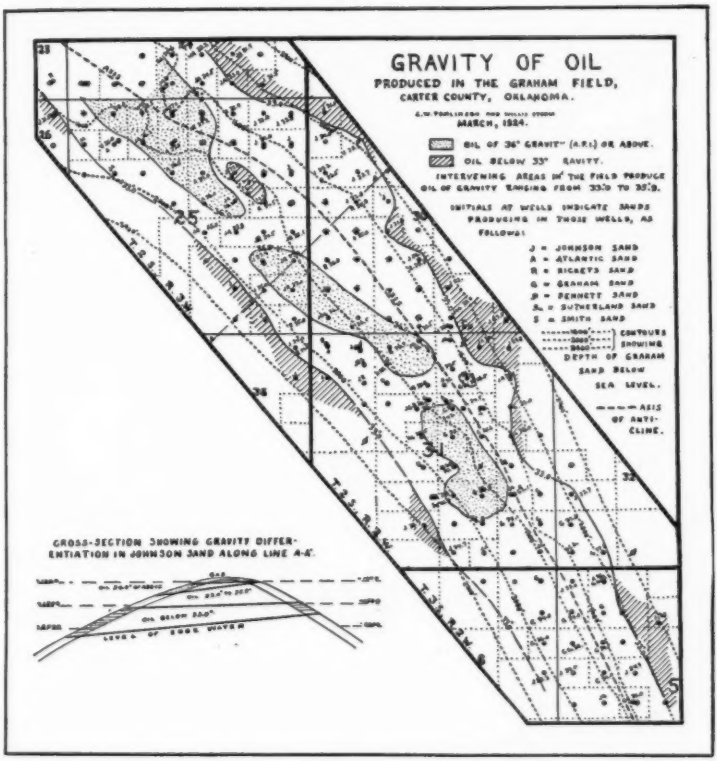
GRAVITY OF OIL
PRODUCED IN THE GRAHAM FIELD,
CARTER COUNTY, OKLAHOMA.
MARCH, 1924.
OIL OF 36° GRAVITY (A.P.I.) OR ABOVE.
OIL BELOW 33° GRAVITY.
INTERVENING AREAS IN THE FIELD PRODUCE OIL OF GRAVITY RANGING FROM 33.0 TO 35.9.
INITIALS AT WELLS INDICATE SANDS PRODUCING IN THOSE WELLS, AS FOLLOWS:
J = JOHNSON SAND
A = ATLANTIC SAND
R = RICKETS SAND
G = GRAHAM SAND
P = PENNETT SAND
S = SUTHERLAND SAND
S = SMITH SAND
CONTOURS SHOWING DEPTH OF GRAHAM SAND BELOW SEA LEVEL.
AXIS OF ANTICLINE.
GROSS-SECTION SHOWING GRAVITY DIFFERENTIATION IN JOHNSON SAND ALONG LINE A-A'.
T.23 N. R.3W.
T.23 N. R.2W.
T.22 N. R.3W.
T.22 N. R.2W.
25
36
32
5

FIG. 4

east corner of the same township the Ordovician rocks of the main Arbuckle area appear, dipping about 45° to the southwest. Bounding them are parallel outcrops of higher formations, to and including the Caney shale (Pennsylvanian), which immediately underlies the Glenn. The basal red beds, representing part of the Pontotoc

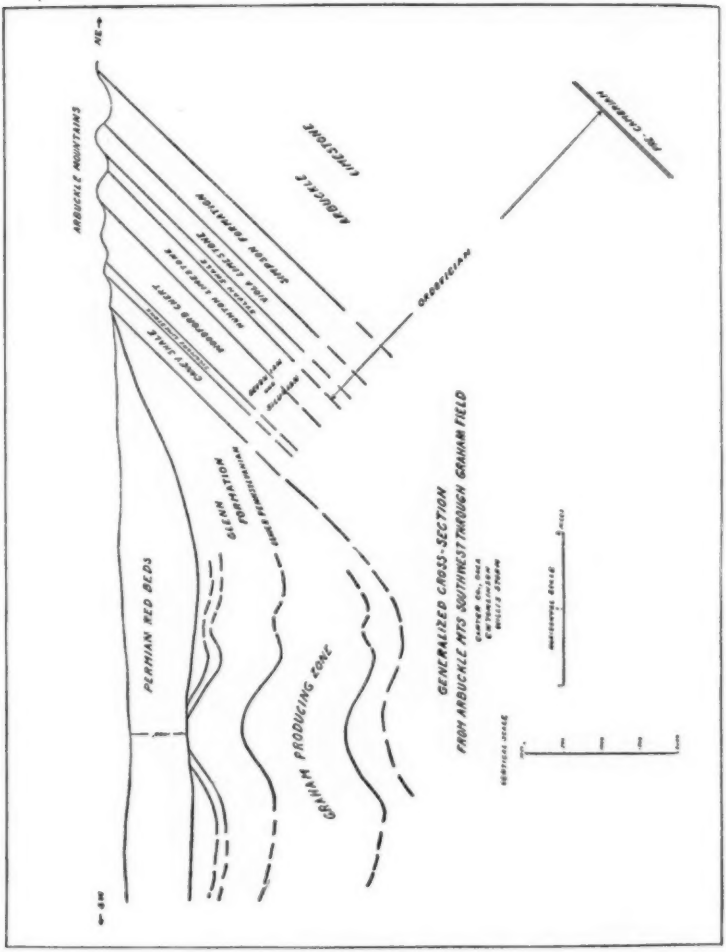

FIG. 5

series,[1] overlap all of these formations, dipping in the same direction at a much gentler angle. Logs of scattered wells between Graham and the mountains indicate that the red beds attain a thickness of

[1] R. A. Birk, "The Extension of a Portion of the Pontotoc Series around the West End of the Arbuckle Mountains." Read before the Houston meeting, A.A.P.G., March 27, 1923.

at least 2,000 feet in this narrow trough. The structural depth of the trough in the underlying Pennsylvanian is probably much greater than this, although it is not certain that the trough is a simple syncline.

The precise structural relation of Graham to the Fox field is uncertain at this writing, although the eastern edge of Fox is only a mile from the nearest existing production in the Graham field. There is a well-marked syncline of substantial depth between the present producing areas of the two fields. The Fox field is made up of an irregular group of much gentler anticlinal structures in the Pennsylvanian which appear, nevertheless, to be better reflected in the structure of the overlying red beds than is the case with the more pronounced Graham anticline.

The Graham field is not yet limited at either end, and seems certain to attain considerably greater length than it has yet reached. The limits of production on the flanks of the fold have been determined only for the first (Johnson) oil sand. Production has been definitely shown to reach farther out on the northeast flank of the structure in the Graham sand than in the Johnson sand, which is 500 feet higher in the section, as one well in Sec. 5, T. 3 S., R. 2 W., which found water in the Johnson sand, obtained oil production in the Graham sand below.

The Graham anticline, like some producing structures in the Rocky Mountain region, belongs to a class of folds representing such close compression that there seems to have been appreciable thickening and thinning of incompetent strata. The thickest incompetent member of the Pennsylvanian section at Graham is a shale, some 400 feet thick, lying between the Kirk gas sand above and the Johnson sand below. In a few wells very close to the axis of the structure, this shale zone appears to have been thickened as much as 25 per cent, causing the productive sands to be reached at depths 100 feet greater than had been anticipated during drilling, from the depth at which the Kirk sand was encountered. Among these is well No. 4 of the Kirk Oil Company and the Hilltop Oil Trust, on the J. H. Bennett farm in Sec. 30, T. 2 S., R. 2 W., and well No. 1 of J. B. Schermerhorn and the Kirk Oil Company on the Hicks Palmer farm in Sec. 5 T. 3 S., R. 2 W. This condition repre-

sents a deviation from the "parallel" type of folding and an approach to the "similar" type.

STRATIGRAPHY

The red beds which form a mantle about 1,000 feet thick over the Graham field and form the surface rocks consist chiefly of buff to brown sandstones, more or less conglomeratic, calcareous and ferruginous, with interbedded shales and clays ranging in color from yellow to maroon. Certain of the sandstones are very calcareous, and there are one or more ledges near the base of the series which are commonly logged as limestone and which may represent the Hart limestone member of the Stratford formation, which is the lowest member of the red-beds series at its nearest surface outcrops.[1]

Small oil production is obtainable from more than one horizon in the red beds. Wells throughout the field and dry holes beyond the limits of Pennsylvanian production log very strong showings of heavy oil in sands from 150 feet to 400 feet deep, such as yielded three or four barrels daily in the earliest wells of the district. A number of gas wells approaching commercial size have been completed in sands near the base of the red beds. These wells were mostly southwest of the main field, up the dip of the red-bed sediments.

The Pennsylvanian section logged in Graham wells includes the following members, listed from the top down (Fig. 6):

1. A group of sandy limes, scattered through 900 feet of blue shales, with sandy lime and sand composing most of the bottom 150 feet of the sequence. This group is represented only in two or three dry holes, as it was entirely removed from the producing area by erosion, prior to the deposition of the red beds.

2. About 400 feet of interbedded blue and reddish or brown shales, more or less sandy.

3. A zone of relatively hard ledges, logged in some wells as sandy lime or lime with interbedded sandstones, and in others as dominantly sandstone with interbedded shales. This zone is about 450 feet thick and is found in most of the edge wells of the field and

[1] R. A. Birk, *op. cit.*

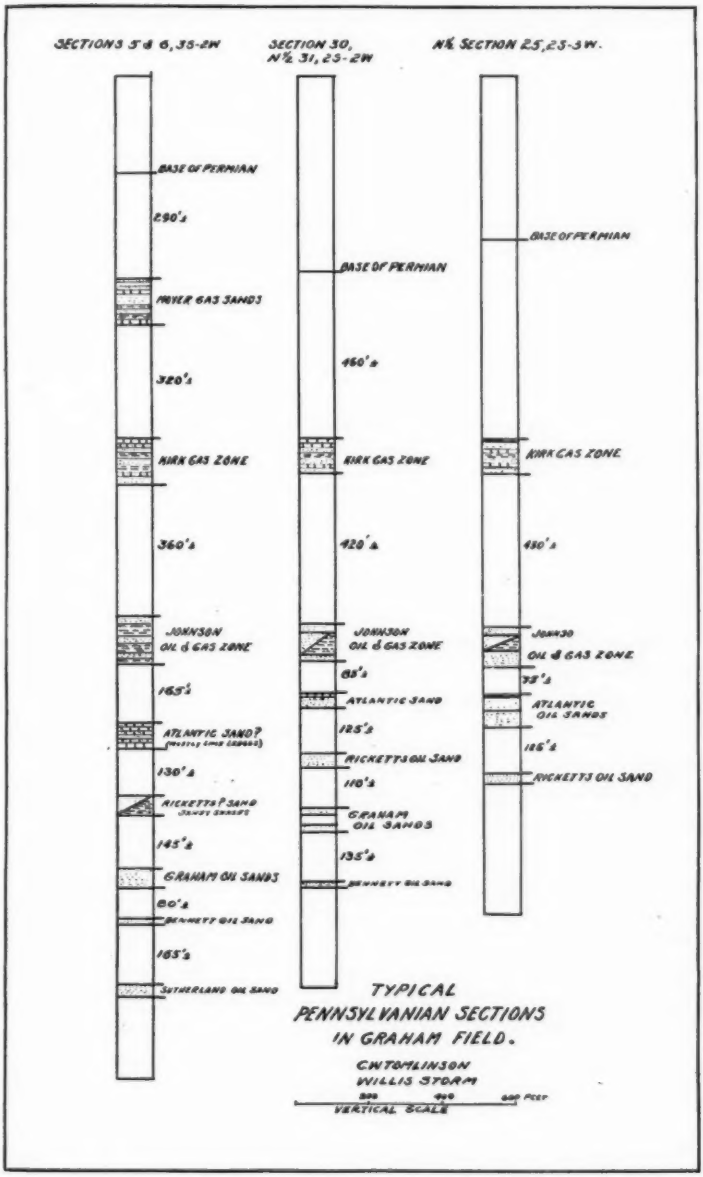
SECTIONS 5 & 6, 3S-2W
SECTION 30, N½ 31, 2S-2W
N½ SECTION 25, 2S-3W.
BASE OF PERMIAN
290'±
PRYOR GAS SANDS
320'±
KIRK GAS ZONE
360'±
JOHNSON OIL & GAS ZONE
165'±
ATLANTIC SAND?
130'±
RICKETTS? SAND
145'±
GRAHAM OIL SANDS
80'±
BENNETT OIL SAND
165'±
SUTHERLAND OIL SAND
BASE OF PERMIAN
460'±
KIRK GAS ZONE
420'±
JOHNSON OIL & GAS ZONE
85'±
ATLANTIC SAND
125'±
RICKETTS OIL SAND
110'±
GRAHAM OIL SANDS
135'±
BENNETT OIL SAND
BASE OF PERMIAN
KIRK GAS ZONE
450'±
JOHNSON OIL & GAS ZONE
73'±
ATLANTIC OIL SANDS
185'±
RICKETTS OIL SAND
TYPICAL PENNSYLVANIAN SECTIONS IN GRAHAM FIELD.
C.W. TOMLINSON
WILLIS STORM
VERTICAL SCALE

FIG. 6

pretty well up the flanks, but was mostly removed by pre-red-bed erosion along the axis of the anticline. In some wells this zone is logged as a group of scattered and relatively thin ledges with thicker intervening shales.

4. A zone about 400 feet thick, made up chiefly of blue shales, with thin sandstone members and lime shells which rarely thicken into ledges as much as 50 feet thick. The sands in this zone and the one above it often yield oil or gas showings and are suspected of having yielded considerable gas in a wild gas well in the southwest corner of Sec. 24, T. 2 S., R. 3 W., which blew in while being drilled by the rotary and was not controlled until it had exhausted itself some months later. These sands have carried salt water, however, in the few wells which have been drilled through them with cable tools.

5. *The Kirk gas sand.*—A sand or zone of sands from 50 to 125 feet thick. This sand has yielded commercial gas in a few wells and doubtless contributed to the flow of the wild gas well in Section 24, but it carries water except in the very highest portions of the structure and has been cased off in most wells. Depth within the field is from 1,300 to 2,400 feet.

6. A zone of blue shales from 400 to 500 feet thick, usually broken by one or two thin sands which yield gas showings. This shale zone is freer from sand or limestone ledges than any other in the sequence, and, as above discussed, shows local thickening at the crest of the anticline. Brown or pink shale is commonly noted near the bottom of this zone, overlying the Johnson sand.

7. *Johnson-Atlantic sand zone.*—This averages about 300 feet in thickness and varies from shale containing only a few thin oil or gas sands to nearly continuous sandstone containing from 25 to 30 per cent of interbedded shale. Its uppermost member, in many places, is a gas sand 10 to 20 feet thick, which carries dry gas more widely than any other producing sand. Below this, and separated from it by 20 to 40 feet of shale, comes the main Johnson sand, which is the chief gas producer of the field and is one of the chief oil sands as well. Its variations in thickness and in initial production are shown on accompanying maps. It is now producing over a wider area than any other sand in the field. It has yielded initial oil

production ranging from 10 or 15 barrels up to 950 barrels daily, and gas wells with initial open-flow capacity ranging from 3,000,000 to 43,000,000 cubic feet daily. Its variation in productivity seems to be controlled in part by the thickness of the sand and in part by structural position with accompanying differences in gravity and viscosity of oil. These factors, however, fail to explain all of the variations noted in the initial production of the sand; and it is probable that differences in coarseness, porosity, degree of cementation, and amount of secondary fracturing also are important influences. Importance of structural position is illustrated by the fact that every well in the field which had more than a 500-barrel initial production is relatively high structurally, and not more than one or two locations removed from the area in which the productive sands carry gas. Depth of the Johnson sand within the area in which it is productive varies from 1,750 to 2,900 feet.

It will be noted that along the axis of the Pennsylvanian fold, the Johnson sand ranges in thickness up to 20 feet with a thickening of a few feet more in Section 25 (Fig. 7). A notable thinning occurs in the southwest quarter of Section 30, and in the east half of Sec. 31, T. 2 S., R. 3 W. Showings of oil and gas are usually recorded from the sand here but practically no production has resulted from tests of it. The wells are usually carried on down to deeper sands.

The maximum thickness of the sand found is in the Humble Oil and Refining Company's No. 1 Burrows in the center of the NW., NE., NE. of Sec. 31, T. 2 S., R. 2 W, where it measures some 100 feet of broken sand. The structural position of this sand body is quite far down on the northeast flank of the fold. Two wells in Sec. 25, T. 2 S., R. 3 W., the Southwestern Petroleum Company's No. 1 Childress, center SE., SE., SE., and the Wirt Franklin No. 1 Gallagher, center NE., SW., NE., found the Johnson pay sand about 60 feet thick. The structural position of these sand bodies is on the southwest flank of the fold but not very far down from the axis.

The Atlantic sand occupies the bottom of this zone and is usually separated from the Johnson sand by a fairly pronounced shale interval, containing thin sandstone ledges. The Atlantic sand in Sec. 25, T. 2 S., R. 3 W., locally yields excellent production, in a

few wells attaining approximately 1,000 barrels' initial daily yield. Much smaller production was obtained from an isolated area in the

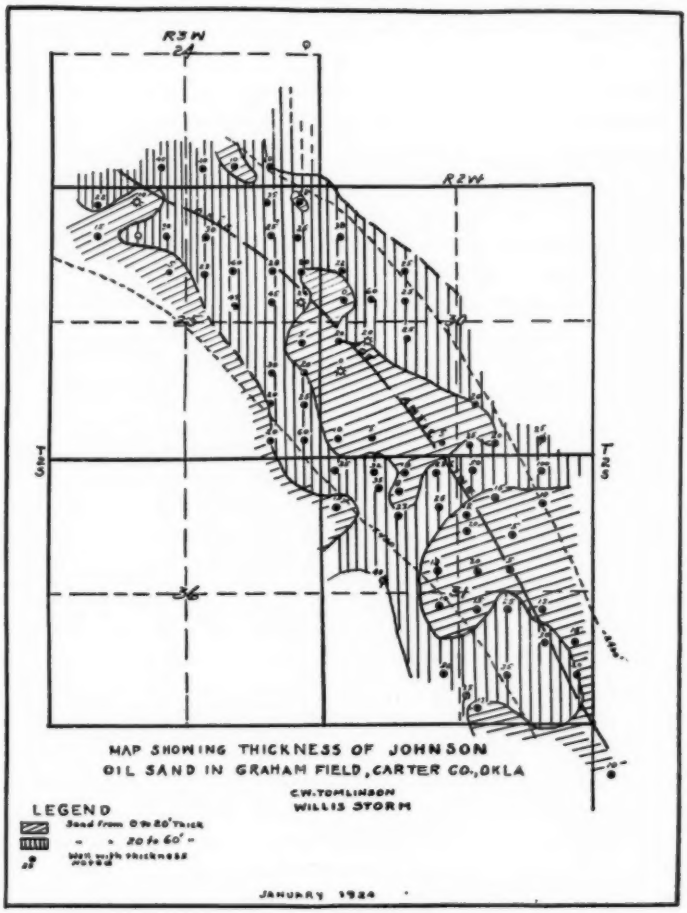

FIG. 7

northwest quarter of Section 31, but through the southern and central parts of the field it is usually barren. This variation seems to be due principally to differences in degree of cementation, as this

sand, where barren, is so tight and calcareous as to be more properly termed a sandy limestone. Most of the logs record a limestone member at this horizon, and it includes limestone ledges even where

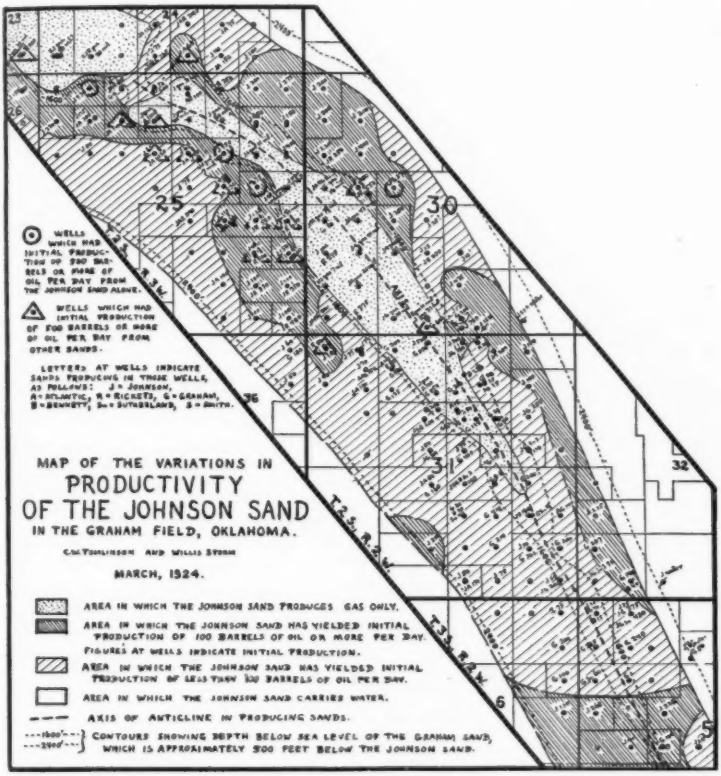
MAP OF THE VARIATIONS IN
PRODUCTIVITY
OF THE JOHNSON SAND
IN THE GRAHAM FIELD, OKLAHOMA.
C.W. TOMLINSON AND WILLIS STORM
MARCH, 1924.
AREA IN WHICH THE JOHNSON SAND PRODUCES GAS ONLY.
AREA IN WHICH THE JOHNSON SAND HAS YIELDED INITIAL PRODUCTION OF 100 BARRELS OF OIL OR MORE PER DAY. FIGURES AT WELLS INDICATE INITIAL PRODUCTION.
AREA IN WHICH THE JOHNSON SAND HAS YIELDED INITIAL PRODUCTION OF LESS THAN 100 BARRELS OF OIL PER DAY.
AREA IN WHICH THE JOHNSON SAND CARRIES WATER.
AXIS OF ANTICLINE IN PRODUCING SANDS.
CONTOURS SHOWING DEPTH BELOW SEA LEVEL OF THE GRAHAM SAND, WHICH IS APPROXIMATELY 300 FEET BELOW THE JOHNSON SAND.
T.3S. R.3W.
T.3S. R.2W.

FIG. 8

it is most productive (Fig. 8). Depth in wells producing from this sand is from 1,950 to 2,800 feet.

8. *Rickets sand zone.*—Between the Atlantic and the Graham sands is an interval of about 250 feet which, in the southern portion of the field, is made up almost wholly of blue shale more or less sandy, with a few thin shells of limestone or sandstone. In the

northwestern half of the field, however, a sand appears near the middle of this interval which develops a local thickness as great as 80 feet and yields the largest initial production yet recorded in the field, approaching 1,200 barrels daily. Depth of the Rickets sand in wells producing from it is from 2,100 to 2,900 feet.

9. *Graham sand.*—This sand, lying 500 or 550 feet below the Johnson oil sand, was the main reliance for production in the earlier developed central portion of the field, where it yielded much better and more uniform production than any of the overlying horizons; hence it came naturally to be called the Graham sand. It usually consists of one or two members only, and varies in thickness from 10 or 15 feet to a maximum of 125 feet. It yields initial production ranging up to a maximum of 500 barrels (Fig. 9). Very few wells in the northwestern half of the field have reached its level. These few have found no solid sand of much consequence in this horizon, suggesting that the Graham sand plays out into sandy shale in that direction. As its present area of production overlaps that of the Rickets sand in only a few wells, and the interval between these two sands, where both are present, is only 100 to 150 feet, there has been some suspicion that the two are identical and that the overlying shales thickened in the southern portion of the field. However, as stated above, both sands are probably present in certain wells in the northwest quarter of Section 31. The apparent coincidence that one sand disappears almost where the other one begins is no more difficult of explanation than the alternative requirement of a sudden sharp increase in thickness of shale, unrelated to structure. Depth of the Graham sand in wells producing from it is from 2,300 to 3,350 feet.

10. *Bennett sand zone.*—Less than a score of wells in the Graham field have penetrated below the Graham sand, and most of these are in the southern half of the field. About a half-dozen wells have reached the Sutherland sand, which appears quite uniformly about 300 feet below the top of the Graham. The interval is made up of blue shales, locally including shales logged as brown or black. A little below the middle of the interval comes the Bennett sand, which varies from a sandy shale without definite sandstone ledges to a sand of one or two members which is 45 feet thick in one well, though

only 10 to 20 feet in most of the others. The maximum initial production credited to this sand is 226 barrels, and it probably exceeded 50 barrels in only one well. It is therefore not a pay horizon

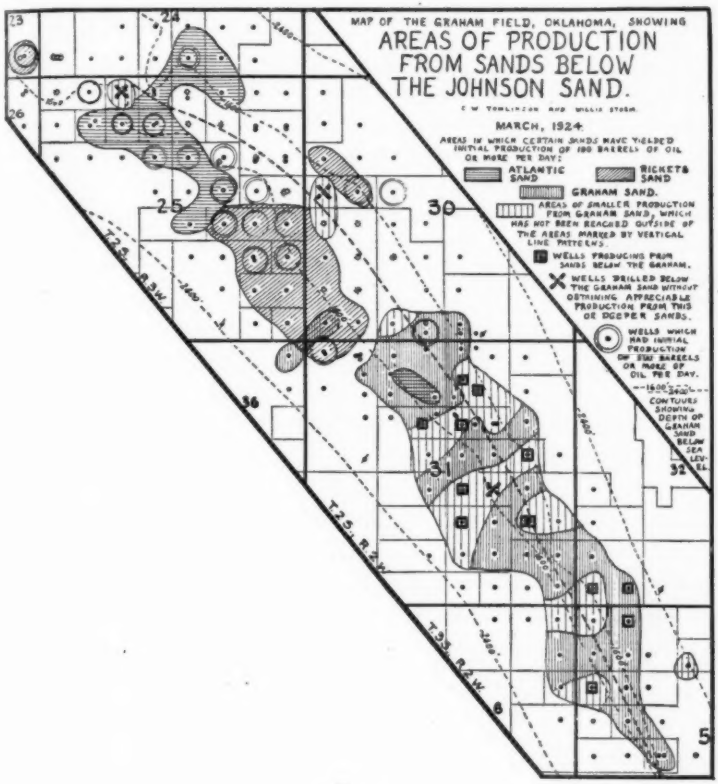

FIG. 9

of much consequence up to this time. Depth of the Bennett sand in wells producing from it is 2,550 to 3,200 feet.

11. *Sutherland sand.*—This sand was first reached in well No. 1 of the Sutherland Petroleum Company on the Poland *et al.* farm in Sec. 5, T. 3 S., R. 2 W., where it had a thickness of about 20 feet. Much oil from upper sands was standing in the hole at the time this

sand was drilled, and it did not begin to flow until the hole was swabbed. Following swabbing, however, the production of the well increased to a figure about 200 barrels greater than the yield it had been making from the upper sands just before the Sutherland sand was reached. It is probable that the major portion of this increase is attributable to production from the Sutherland sand. This is a relatively hard sand containing a semicrystalline calcareous cement. In no other well does it appear to have yielded initial production exceeding 25 barrels, although a maximum thickness of 40 feet has been reported. Depth of this sand in wells producing from it is from 2,700 to 3,700 feet.

12. *Deeper levels.*—The maximum stratigraphic depth which has been reached in the field is about 400 feet below the Sutherland sand. Four deep wells have reached a sand, called the Smith sand, 250 to 350 feet below the Sutherland sand. This ranges from 10 to 30 feet in thickness, but is very hard and close-grained and probably has not yielded over 25 barrels initial production in any well. Depth of the Smith sand in wells producing from it is from 3,200 to 3,400 feet.

CORRELATION OF THE GRAHAM PENNSYLVANIAN SECTION WITH OTHER AREAS

No positive assertion can be made at this time regarding the position of the sequence described above in the Glenn formation. It has even been suggested that it may belong to a post-Glenn formation of Upper Pennsylvanian age. A few fossils from the Johnson sand and other pay horizons have been identified by Dr. Girty, of the United States Geological Survey, but they are long-range types which cannot be definitely assigned to any particular part of the Pennsylvanian. Dr. Girty suggested that they were similar to the fauna of the Strawn formation of Texas.[1]

In view of the narrowness of the synclinal area between Graham and the Arbuckle Mountains it is not likely that formations younger than the Glenn could appear under the Permian in normal sequence and be reached so as to constitute the section penetrated in Graham wells. On the other hand, the Graham section does not resemble very closely the sequence of ledges in the basal portion (Springer

[1] Letter to Willis Storm, 1923.

member[1]) of the Glenn as exposed from 10 to 20 miles east of Graham, on the southern front of the Arbuckles. It seems probable that the top of the Caney shale has not been reached in Graham wells, and that there may be additional Pennsylvanian sands to be found below the maximum depth which has yet been reached.

In the Hewitt, Healdton, and Brock fields, all in the same county as Graham, ridges of buried hills of Ordovician and Silurian limestone immediately underlie the Pennsylvanian oil-bearing sequence, at considerably less depth than that which has already been reached at Graham; and oil production has been obtained from the buried early Paleozoics in all three of these fields. If such an Ordovician core exists in the Graham anticline, there is no satisfactory means of predicting the depth at which it will be found.

It is possible that the oil-bearing series at Graham is the same as that in the Hewitt field and in the recently discovered field in T. 1 S., R. 3 W.

GRAVITY OF OIL

One of the most interesting features of the Graham field is the distribution within it of different grades of oil, ranging from a minimum of 27.5° Baumé to a maximum of 43° Baumé. Oil above 39° in gravity has been obtained only from the deep Sutherland and Smith sands, and oil below 32° in gravity, with one exception, has been obtained only from the Johnson sand, the shallowest of the Pennsylvanian oil-bearing sequence at Graham. Oil from the Atlantic, Rickets, Graham, and Bennett sands ranges from 32.5° to 38° in gravity, except for a single well producing lower-grade oil from the Graham sand far down on the flank of the structure, where the gravity is below 30°.

In each of the sands which have been widely developed there is a marked vertical gradation in gravity, with the lightest oil highest on the structure and the heaviest near the edge-water line. This condition is best shown by the Johnson sand, which is more widely developed than any other in the field at this time (Fig. 4). In the accompanying map showing the variations in gravity of oil in the field, no division into the production of separate sands has been

[1] Upper part of the Caney shale, according to Girty & Roundy, "Notes on the Glenn Formation of Oklahoma," *Bull. Amer. Assoc. Pet. Geol.*, Vol. 7 (1923), pp. 331–49.

attempted, although the sands producing in each well have been indicated on the map, and all available data are also given as to gravity of oil from different sands in the same well. Within the Johnson sand alone there is a range in gravity from 27.5° up to 38° Baumé. The lines on the map separating areas producing oil of different grades show a surprisingly close parallelism to structure contours. This is somewhat modified by the asymmetry of accumulation, as oil extends about 350 feet farther down the southwest flank of the fold in the Johnson sand than down the northeast flank. Gas in this sand has adjusted itself more perfectly to the structural and gravitational control than is true of the oil, so that nearly all of the oil of higher than 36 gravity appears in the upper portion of the southwestern flank of the fold, in a strip paralleling the axis.

It seems to the writers that the most satisfactory explanation of this remarkable vertical differentiation in gravity of oil is to be found along the lines of the old interpretation of the structural theory of accumulation of oil; and that the observed condition is due, either to actual segregation of different qualities of oil in the same sand under the influence of gravitation, or to preservation, because of differences in gravity, of a vertical variation which may have been brought about chiefly in connection with the migration of gas through the oil body up to the crest of the fold. Gas bubbles rising through the oil column would tend to carry with them in solution, and as covering films, the lighter rather than the heavier constituents of the oil; and the lighter constituents would therefore gradually accumulate toward the gas contact, leaving the heavier residuum behind close to the water level. Vertical differentiation has doubtless been aided by the steep dips of the oil-bearing sands. This factor probably is entirely responsible for the exceptional development of gravitational differentiation of oil in the Graham field.

It does not seem probable that grades of oil varying as widely in gravity as those present in the Johnson sand at Graham were originally fed into the sand from the source rocks. The greater part of the differentiation is believed to have taken place during, or during and after, accumulation of the oil into the Graham pool.

The source rocks are believed to have been shales of the Glenn formation, with possible contributions from the underlying Caney

shale. In the 700-foot series of sands from the Johnson to the Bennett, inclusive, there is no marked difference in gravity between one sand and another, if the full range of gravity in each sand be considered. The Sutherland and Smith sands, which have been reached only near the axis of the anticline, show a maximum gravity several degrees higher than the maximum produced from the upper sands, suggesting an improvement in quality of oil with increasing stratigraphic depth in the same conformable sequence of rocks.

The above-described conditions in the Graham field are analogous to those stated by John B. Stevens[1] as characteristic of the Buena Vista and Elk Hills anticlines in California. Oils growing heavier with increasing structural depth seem to be a not uncommon feature of steep anticlinal fields. This condition does not conflict with the more widely observed condition of oils growing lighter with increasing *stratigraphic* depth which, as noted by E. G. Gaylord,[2] occurs in the same Californian fields.

ULTIMATE PRODUCTION

The following table gives data as to the present production of different parts of the field in relation to the initial production of the same areas and the age of the wells:

TABLE I

(*a*) Sections	(*b*) No. Oil Wells	(*c*) Total Initial Production	(*d*) Total Present Production	(*e*) Average Initial Production	(*f*) Average Present Production	(*f*)÷(*e*) Per Cent	(*g*) Average Age of Wells in Months
31, 36.....	51	8,479	2,855	166	56	33	12
25.....	33	15,593	7,295	473	221	47	4
30.....	21	5,787	1,915	276	91	33	10
23, 24, 26...	9	2,292	1,155	255	128	50	3½
5, 6, 32.....	18	3,205	1,575	178	88	50	3
Entire field	132	35,356	14,795	268	112	42	7½

A field-decline curve can be drawn from the data given above, based on the different average age of wells in the different parts of the field, with the percentage ratio in each section between present

[1] John B. Stevens, "A Comparative Study of the San Joaquin Valley Oil Fields," *Bull. Amer. Assoc. Pet. Geol.*, Vol. 8 (1924), p. 38.

[2] E. G. Gaylord, discussion of Mr. Stevens' paper, *op. cit.*, pp. 39–40.

production and total initial production. Such a curve shows an absurdly long life for the field, and is not reproduced here because it is misleading. The production in the south half of the field is coming chiefly from the Graham and deeper sands, which are not producing in the northern half of the field. Wells in the Graham sand and deeper sands show an average initial production smaller than is true of the shallower sands in the northern portion of the field, but decline more slowly than the latter (Figs. 2 and 10). Therefore, a curve based on wells three or four months old in the shallow sands and on wells ten or twelve months old in the deep sands will show an undue flattening in the latter half of the first year of production.

Nevertheless, it is believed that the Graham field will have a very long life. Decline curves carefully worked out for wells in all parts of the field indicate a commercially productive life of not less than twenty years for many wells. Above the 2,000-foot contour on the accompanying structure map, that is, within two-thirds of the area of the field, no water is found in any of the Pennsylvanian oil-bearing sands, from the Johnson down. Within this area there is no intermediate water to interfere with production. The encroachment of edge water is confidently expected to be systematic and slow, and no beginning of that process can yet be discerned.

From the sands at present developed, an ultimate yield ranging from 7,000 to 25,000 barrels per acre is expected, with an average between 10,000 and 15,000 barrels. The field so far is not so prolific as Hewitt or Healdton, but shares the quality of long life shown by those fields. Up to November 1, 1923, the average yield per acre of the Hewitt field was about 14,500 barrels and of the Healdton field over 25,000 barrels.

The early development of the field was begun with wells in 150-foot locations, and the drilling of certain properties in Section 31 was planned for a spacing of 5 acres per well. The production records of these properties to date indicate an ultimate yield from 50 to 100 per cent greater than is indicated for other parts of the same section where a spacing of 10 acres per well has been followed. Allowing for differences in productivity of sands, the more closely spaced properties show an advantage of about 60 per cent when compared with other properties of similar initial production from

the same sands. Nevertheless, the 10-acre spacing which has been followed throughout the more recently developed portions of the field was doubtless a wholesome thing, in view of the depressed oil

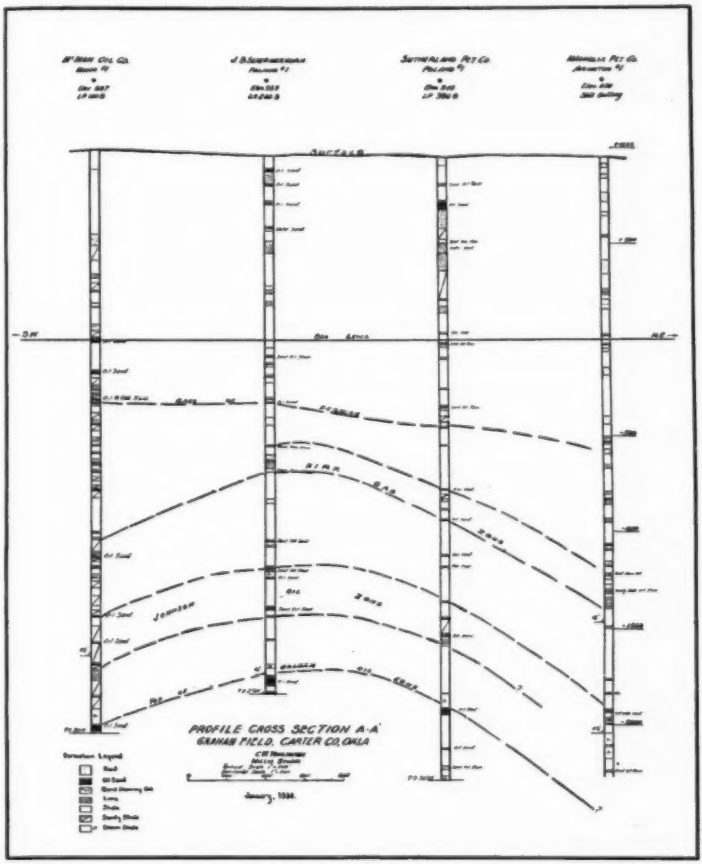

FIG. 10

market through the year 1923. For some portions of the field the 10-acre spacing is apt to prove more profitable, even in the long run, than closer spacing.

A condition of interest in connection with the spacing problem is the demonstrated existence at several points in the field of very rapid changes in character and thickness of some of the producing sands. Perhaps the most striking case is that of wells Nos. 2 and 3 of the Cameron Refining Company on the O. S. Sparks farm in Sec. 30, T. 2 S., R. 2 W. Well No. 2 logged 95 feet of solid productive oil sand at the horizon of the Johnson sand. Well No. 3, which is only 180 feet from No. 2, logged only 25 feet of oil sand representing the same horizon. Well No. 2 showed an initial production of 380 barrels natural flow, whereas well No. 3 refused to flow persistently and yielded less than 100 barrels maximum production from this horizon. Where such variations exist, wide spacing cannot be expected to find all of the rich portions of the sand, but, on the other hand, close spacing in a lean area might result in economic loss. The oldest developed property in the field had yielded 4,500 barrels per acre up to the close of 1923, from 6 wells on 40 acres, averaging about one year old.

DEVELOPMENT METHODS

The use of cable tools in the Graham field has been fraught with serious difficulties, arising chiefly from two causes: (1) the steep dip of the beds, which causes a tendency toward a crooked hole; and (2) the presence of shales with an almost unconquerable habit of caving. As a result of these difficulties six or eight cable-tool holes in the field have had to be abandoned without reaching their destinations. Rotary tools, especially if forced to make hole too rapidly, also leave crooked holes, but in no case have the rotary tools failed for this reason to reach the desired depth.

The most common practice in the field has been to drill with the rotary to or almost to the top of the first pay sand, cementing $8\frac{1}{4}$-inch casing at that point and drilling in with cable tools. Where only one sand is developed in a well and the $8\frac{1}{4}$-inch casing is set just at the top of that sand, this method works admirably, and by many of the operators it is considered the ideal method even when a considerable depth must be drilled by the cable tools in order to reach the pay or to carry the hole to lower sands.

However, deepening with cable tools for any great distance through shales has been very slow, expensive work, and in a few cases has failed to reach the depth desired. Therefore, a few operators have experimented by completing wells entirely with rotary tools. There is wide divergence of opinion among the operators in the field as to the relative success of the two methods of completion. A detailed statistical study of the results of the two methods is given in the following table:

TABLE II*

COMPARISON OF RESULTS OF ROTARY AND CABLE-TOOL COMPLETIONS

Twp. Rge. Section	Number of Completed Wells		Total	Average Initial Production		
	Cable-Tool Completions	Rotary Completions		Cable-Tool Completions	Rotary Completions	Total
	Oil Wells					
2 S. 3 W. 23.....	1	0	1	500†	.....	500†
2 S. 3 W. 24.....	3	4	7	172	282†	235
2 S. 3 W. 25.....	27	6	33	471	480	473
2 S. 3 W. 26.....	1	0	1	150	.....	150
2 S. 3 W. 36.....	2	0	2	115	.....	115
2 S. 2 W. 30.....	20	1	21	277	250	276
2 S. 2 W. 31.....	41	8	49	169	166	168
2 S. 2 W. 32.....	3	1	4	217	90	186
3 S. 2 W. 5.....	6	4	10	222	152	194
3 S. 2 W. 6.....	4	0	4	131	.....	131
Entire field....	108	24	132	269	262	268
	Gas Wells					
2 S. 3 W. 23.....	1	0	1	10††	.....	10††
2 S. 3 W. 24.....	0	2	2	.....	35††	35
2 S. 3 W. 25.....	2	4	6	10	23	18
2 S. 2 W. 30.....	3	5	8	16	25	22
Entire field....	6	11	17	13	26	21

* All wells in which the producing sands were drilled through with rotary tools are classed as rotary completions. The maximum single-day production is taken as the initial production of each oil well; in the case of some of the cable-tool completions this maximum yield was obtained after deepening to a second or third sand.

† Barrels.

†† Millions of cubic feet.

It will be noted that the average initial production of the 24 oil wells completed with rotary tools has been almost identically the same as the average initial production of the 108 oil wells which have

been completed with cable tools. There is a difference of $2\frac{1}{2}$ per cent in favor of the cable-tool completions. In the sections of highest average initial production, Sections 24 and 25, the rotary completions show an average initial production greater than that of the cable-tool wells. The sands involved in the two kinds of completions are on the average the same, as nearly all the wells in this section have been carried to either the Atlantic or the Rickets sand.

Lest cable-tool advocates feel an unfairness in the foregoing figures because of the higher proportion of cable-tool completions in areas of smaller average yield, it should be noted that in Section 31, which has the smallest average initial production of any section in which completions of both types have been made, the average initial production of wells completed with the rotary has been less than 2 per cent under the average for cable-tool completions. The conclusion is not justifiable, therefore, that rotary completions are successful where the yield is large but unsuccessful where the yield is small. The poor showing of the rotary in Sections 32 and 5 might suggest this; but two of the four best wells in Section 5 were completed with the rotary, although the other two rotary completions in that section were disappointing. It should be recorded in this connection that three wells in the field have been drilled with cable tools through sands yielding profitable production in offset wells, without obtaining any commercial production whatever in the three wells in question. None of these wells is yet regarded as finally completed, so they are not included in the averages computed above for cable tools. If they were included they would reduce the good showing made by the cable tools.

No one claims that injury to the sand by cable-tool completions is responsible for their inferior showing in Sections 24 and 25 as compared with rotary completion. Therefore there is only a theoretical basis on which the rotary can be blamed for its three inferior completions in Sections 5 and 32, and the number of these completions is too small to afford adequate basis for generalization. These three wells are included in the general average for rotary completions in the field, which, nevertheless, holds its own well with the cable-tool average.

As further testimony along the same line, it is noteworthy that the eleven gas wells which have been completed with the rotary show an average initial open-flow capacity just twice as great as the average for the six gas wells which have been completed with cable tools. It is not to be supposed that the method of completion had anything to do with this result.

Among the wells completed with the rotary, the most serious disappointments have been in cases in which rotary drilling was carried on for two or more weeks after the chief pay sand had been penetrated. In the majority of the most successful rotary completions the rotary tools were not at work long after the chief pay was drilled through. On the other hand, one of the very best rotary completions, well No. 1 of Wirt Franklin on the Gallagher farm in Sec. 25, T. 2 S., R. 3 W., was shut in for six weeks with the rotary mud on the sand during the proration period in the summer of 1923, before the plugs were drilled. In well No. 3 of J. B. Schermerhorn on the Holman farm in Sec. 24, T. 2 S., R. 3 W., the largest well yet completed in that section, the rotary tools were at work for two weeks in drilling through the Johnson-Atlantic sand zone. An offset well completed with cable tools was carried through these sands and additional deeper sands, but obtained less than half the initial production of this well. There is as great a difference in results between adjacent cable-tool completions in many parts of the field as between any cable-tool completion and an offsetting rotary completion.

Rotary completions of inside wells later in the history of the field, after most of the gas pressure is gone from the sands, may not turn out so well in comparison with cable-tool completions under the same circumstances, as there will be less resistance to penetration by rotary mud, and less force left in the sands wherewith to clean themselves after such penetration. That a temporary setback is given to production in some cases by rotary completion is indicated by several Graham wells so completed, which have increased notably in daily yield for several days or even weeks after completion, and have shown remarkable persistence in maintaining very nearly their initial yield for two or three months. A comparison of the first month's production of the wells completed by the two methods

probably would be more favorable to the rotary than the foregoing comparison of initial yields. The most rapid declines in the field have been shown by certain cable-tool completions, all of which are close to the edge of the gas-producing area. The average number of productive sands in the rotary completions at Graham is about the same as in the cable-tool completions. Certain cable-tool wells have penetrated all of the known producing horizons at Graham in the same well, and this can also be said of two of the rotary completions. It is not believed that the rotary completions have any unfair advantage over the cable-tool holes in the foregoing comparison because of this factor. The only rotary completions which have been carried through more than the average number of producing horizons were those which had very poor showings in the upper sands, and none of these wells obtained an initial production equal to the average. The high average initial production of the rotary completions is due chiefly to wells completed in only one or two producing horizons.

THE OIL HORIZONS OF KENTUCKY, NORTHEASTERN MISSISSIPPI, AND TENNESSEE

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INTRODUCTION

As so much of the entire geologic column is exposed in Tennessee, where it can be studied from the Archean rocks along the North Carolina line to the Quaternary formations along the Mississippi River, one may here establish a close acquaintanceship with those horizons which in Kentucky and Tennessee have produced oil, where their depth beneath the surface and porosity and structure are favorable. With the deeper drilling that is being carried on each year, and the findings of oil sands and producing wells in the older formations, it is of interest to know something of the thickness, extent, and character of the different formations from which this oil is produced.

ORDOVICIAN OIL HORIZONS

During 1922 a new pool was opened on Kettle Creek, along the Kentucky-Tennessee line, in the southeast corner of Monroe County, Kentucky. A recent study of this area shows that the oil comes from horizons 240 feet, 260 feet, and 535 feet below the Chattanooga black shale, and that the base of the Trenton formation occurs 535 feet below the base of the Chattanooga black shale, or 20 feet above the bed of bentonite found in these wells and known as "pencil cave."

To the south in Tennessee, the horizons of these oil sands come to the surface in the vicinity of Carthage Junction. The oil occurring 535 feet below the Chattanooga black shale comes from the base of the Hermitage formation. This is the original "Sunnybrook" sand which has produced oil in a few restricted areas. The Hermitage formation was laid down in a sea which extended northward from the Gulf of Mexico and covered most of middle

Tennessee and practically all of Kentucky, as well as several of the northern states. It appears that the lower Sunnybrook sand occurs in the base of the Hermitage.

The two upper oil horizons at 240 and 260 feet below the Chattanooga black shale occur in a formation known as the "Cannon limestone" of the Trenton group. The exact relationship of this formation (which is named from Cannon County, Tennessee), to the Trenton group was worked out during the summer of 1922 by Dr. R. S. Bassler and E. O. Ulrich. The Cannon formation is composed of layers of dove and gray limestone, both porous and tight. Just southwest of the Kettle Creek pool, in Cannon County, Tennessee, this formation, which is there well exposed, has a thickness of 250 feet, while at Nashville, Tennessee, 75 miles to the west, it is either absent or only 5 to 25 feet thick. The entire extent of the Cannon sea has not yet been worked out, but we know that its western shore line was in the vicinity of Nashville in north-middle Tennessee, and around Fayetteville, Tennessee, just north of the Alabama line. The fact that this formation is absent or very thin on the western side of the Nashville dome would account for the fact that in this section no oil in paying quantities has been found several hundred feet below the black shale, even where favorable structure existed. The good shows of oil found in shallow wells 50 to 100 feet deep around Fayetteville, Tennessee, come from this formation, and indicate that this horizon may produce commercial wells on well-defined small structures along the eastern Highland Rim of Tennessee.

The oldest oil sand in this region known to date occurs on the northeast flank of the Nashville dome, in Pickett County, Tennessee, and in Clinton and Warren counties, Kentucky. This oil horizon was first found in a well drilled on Holbert Creek, Pickett County, Tennessee, at a depth of 1,335 feet below the Chattanooga black shale, and 800 feet below the base of the Trenton.

In Clinton County, Kentucky, a well drilled in Beech Bottoms in 1922 encountered this sand 1,375 feet below the Chattanooga and 790 feet below the base of the Trenton. The sand is 10 feet thick.

To the southwest of these wells are exposures of lower Ordovician rocks, including 100 feet of the Black River group and 345 feet of the Stones River group, with the base of the Ordovician still exposed; while to the southeast in Hancock County, about six miles west of Sneedville, there is exposed below the base of the Trenton the Lowville formation, here having a thickness of about 700 feet, and below it about 100 feet of very crystalline limestone resting on the top of the Stones River group of the Ordovician.[1] This shows that an abnormal thickness of lower Ordovician rocks belonging to the Black River group was deposited on the northeast flank of the Nashville dome. Considering that the formations of this group thicken at a uniform rate to the northeast toward Pickett County, Tennessee, as it is supposed they do to the northeast toward Hancock County, one could estimate the thickness of the rocks belonging to the Black River group as about 400 feet, which, with the known thickness of the lowest Ordovician rocks belonging to the Stones River group, 300 feet, indicates that this lowest oil horizon occurs just above the base of the Ordovician, and just above rocks of Canadian age.

In December, 1922, a well drilled in Warren County, Kentucky, 4½ miles east of Bowling Green, drilled into an oil sand at a depth of 1,697 feet below the Chattanooga black shale. The log and cuttings of the well did not permit positive identification of the base of the Trenton, yet on the best evidence available which takes account of the considerable thickness of both Devonian and Silurian rocks in this part of Kentucky, it was placed at 987 feet below the Chattanooga black shale. The thickness of lower Ordovician rocks belonging to the Stones River and Black River groups just south of Warren County, Kentucky, around Nashville, total practically this amount. On page 624 is a log of this well.

We have now described the oil and gas horizons of Ordovician, or possibly older ages, all of which produce only a meager amount of oil, but which may be a source of much more oil in the future.

[1] E. O. Ulrich, personal communication (1922).

TEXAS RADIO NO. 1 WELL ON WALTER PHILLIPS LEASE ON PORTER PIKE, 4½ MILES EAST OF BOWLING GREEN, KENTUCKY:

	Feet	Feet	
Gray limestone	0	525	
Black shale (Chattanooga)	525	603	
Gray limestone	603	618	
Blue limestone	618	643	
Oil show	643	653	
Brown limestone sand	653	683	
Blue limestone sand	683	698	
Brown limestone sand	698	725	
Blue limestone sand	725	765	
Brown limestone sand	765	780	
Blue limestone sand	780	805	
Brown limestone sand	805	875	
Gray limestone sand	875	905	
Blue limestone sand	905	925	
Brown limestone sand	925	945	
Blue limestone sand	945	980	
Brown limestone sand	980	1,005	
Pink limestone sand	1,005	1,010	
Gray limestone sand	1,010	1,025	
Black limestone sand	1,025	1,255	
Brown limestone sand	1,255	1,340	
Gray limestone sand	1,340	1,400	
Black limestone sand	1,400	1,590	
Brown limestone sand	1,590	1,730	
Blue limestone sand	1,730	1,780	
Salt water (some at 1,780 feet)			
Brown sand oil (with chloroform)	1,780	1,795	
Brown limestone	1,795	1,835	
Brown rainbow oil showing	1,835	1,840	
Brown limestone (oil)	1,840	1,849	
Brown limestone	1,849	2,300	
Oil sand	2,300	2,315	(800 ft. below) Trenton
Sandy gray dolomite	2,315	2,320	
Gray dolomite	2,320	2,338	
Light brown dolomite, sandy at bottom	2,338	2,360	
Very hard light brown dolomite	2,360	2,381	
Light brown hard dolomite	2,381	2,391	
Artesian water (rose 1,000 feet salt water)			
Gray sandy dolomite (2d specimen)	2,391 to 2,395 bottom		

SILURIAN OIL HORIZONS

The principal oil production of the Kentucky-Tennessee region comes from sands in strata of Silurian, Devonian, or Carboniferous age. Of these, the most important from a production standpoint is the "Corniferous" formation of Devonian age, which is a limestone or dolomite. The location of the old shore line of the Corniferous, or, as it is known in Tennessee, Pegram limestone, is important. Exposures of this limestone are not known south of Petroleum, a town in the southern part of Allen County, Kentucky. No outcrops are known in Sumner County, Tennessee, but it does appear again 12 miles west of Nashville, at Newsom Station, where it has a thickness of 3 feet, while a few miles farther west, at Pegram, in Cheatham County, it has a thickness of 12 feet. From these exposures, it would appear that the old shore line of this Devonian limestone formation extends from Newsom Station northeastward through Cheatham and Robertson counties, Tennessee, probably passing in the vicinity of Springfield, Tennessee, and then crossing over the state line in the proximity of the northeast corner of Robertson County, near Mitchellville. All territory as far west of this area as Tennessee River is underlain by Devonian limestones. This formation of the Onondaga group was deposited in a sea which covered the western half of Kentucky with an embayment extending eastward, and covering only the northwestern part of middle Tennessee. Considerable production is obtained from this formation in the Big Sinking pool in eastern Kentucky, one of the largest oil pools in the state.

In Allen County, Kentucky, around Scottsville, the oil is found in three different horizons below the Chattanooga black shale. These three sands are not always present at one place, and, when present, as a rule, only one is productive. The upper, and sometimes the upper two, sands are considered Devonian, and probably correlate in Tennessee with the Pegram limestone. The lower sand, which produces most of the oil south of Scottsville, is thought to be Silurian and to be Louisville limestone, as this formation outcrops in Sumner County, Tennessee, just south of Allen County, Kentucky, at the base of the Chattanooga black shale, the Corniferous beds of Devonian age being absent.

The shore line of the Silurian Louisville limestone is of interest, in regard to the effect it may have on possible oil territory in the counties on the western Highland Rim of Tennessee. In Sumner County, south of Westmoreland, it is 20 feet thick, while about 25 miles to the southwest, near Ridgetop, in Robertson County, it only shows a thickness of 10 feet. Farther southwest, in southern Cheatham County, around Pegram, it is very thin, having about a 15-foot exposure. On the western edge of the Highland Rim, along Tennessee River, this formation changes to a shaly phase, known as the Lobelville, which varies in thickness from 10 to 75 feet. These facts indicate that the extent of the limestone phase of the Louisville formation lies just to the southeast of the present edge of the Highland Rim on the Middle Basin of Tennessee, as far south as Pegram, and that at this point the line turns to the northwest, swinging back into Kentucky. The extreme thinness of the formation, except in the northern part of Sumner County, Tennessee, and probably in the northern part of Robertson County, Tennessee, indicates that only in these two areas is it thick enough to act as a commercial oil reservoir. The long embayments in which this and the overlying formations were laid down makes it probable that there are even areas in the northern Highland Rim counties of Tennessee lying outside of these old embayment areas, in which these formations were never deposited. In the more southern counties of the Highland Rim west of Nashville, overlapping formations come in between the Louisville limestone and the Chattanooga black shale, which may keep this formation from containing oil, if such oil is derived from the Chattanooga black shale. That this formation is probably absent in the southwestern part of Robertson County is indicated by the fact that a well drilled in 1919 on Sulphur Fork, six miles southwest of Cedar Hill, which went to a depth of 1,015 feet, and passed through the Chattanooga at 615 feet, encountered no water, oil, or gas below this formation. This hole probably passed through rocks of Trenton age at 950 feet, the presence of blue phosphate sand in the limestone above this level being taken as evidence of the presence of the Hermitage formation of Trenton age at this depth.

In Kentucky, outside of production in Warren, Allen, and adjoining counties, which is considered to have come from this formation, it is considered probable that much of the production from the eastern part of the state, which has always been considered to have come from the Corniferous, may in reality come from the Louisville formation of Niagaran age, as the sea of that time covered practically all of Kentucky except the extreme eastern part, and as the formation contains in many places thick coral reefs, which form excellent reservoirs in which oil could accumulate.

MISSISSIPPIAN OIL HORIZONS

The best-known formation, which is used as a marker by the drillers in Kentucky and Tennessee, is the Chattanooga black shale, lying next above a great unconformity and probably of Mississippian age. The rocks which immediately underlie the Chattanooga in different places vary in age from Onondaga, of Middle Devonian age, down to the Trenton, of Ordovician age. The Chattanooga black shale is the great overlapping formation of this region. However, due to the great unconformity at its base, one cannot use the distance of a sand below the Chattanooga black shale as a method of correlation with another sand found the same distance below the Chattanooga black shale in another county or distant section of the state.

In the last two years we have found a horizon marker below the Chattanooga black shale, which can be used as a positive tie point in interpreting and correlating well logs. This is a bed of bentonite, an altered volcanic ash, a green sticky clay, two to four feet thick, containing mica flakes, which occurs about ten feet below the base of the Trenton group. Where drilling has been done this is 387 to 550 feet below the Chattanooga black shale. In places, there is a second thinner bed of bentonite, 20 feet below the upper bed. Both of the beds are called "pencil cave" by the drillers.

The Chattanooga black shale is an oil shale, and in places in Kentucky and Tennessee has yielded, on distillation tests, over 40 gallons of oil to the ton. It is possible that the upper part of the Chattanooga, where the shale is over 10 feet thick, is not part of

the true Chattanooga formation, but is possibly a southern extension of the Sunbury shale. Throughout Tennessee, the upper part of the Chattanooga black shale is separated from the lower part by a sandy layer 1–2 inches thick.

It has been thought by some[1] that this sandy layer may represent the southern extension of the Berea sandstone. Fossil fragments found in this sandy layer have led Ulrich to believe this may represent the Berea. Whether this interpretation of the southward thinning of the Berea and the overlying Sunbury shales is correct, or whether these formations were never deposited this far south, it is certain that the well-known Beaver sand of southern Kentucky occurs stratigraphically above the Berea sand, which occurs in the northeastern part of the state. The Beaver sand occurs in the base of the New Providence formation and is a producing horizon of importance in southern Kentucky. Stratigraphically this formation occurs high up in the rocks of Mississippian age, as it is a part of the Osage group, while the Berea formation occurs practically at the base of the Mississippian series. The Berea does not occur as an oil horizon south of Kentucky, but the Beaver sand does occur in the Highland Rim section of Tennessee, and may be found productive in favorable places.

The Weir sand which is found in east Kentucky is a sandstone formation 30 to 60 feet thick, belonging to the Kinderhook group of the Mississippian. Wells in this sand produce from 5 to 35 barrels of brownish-green oil of high gravity. Stratigraphically this sand is likewise below the Beaver sand of the New Providence formation. The first oil horizon lying stratigraphically above the Beaver sand is the Big Injun sand, which is a calcareous sandstone, occurring in a formation equivalent to the Fort Payne chert of southern Kentucky and Tennessee. In the past the Fort Payne chert has produced oil in the Springer oil field, Overton County, Tennessee, from shallow wells less than 200 feet deep. This pool is now abandoned, but it is reasonable to expect similar pools in nearby areas.

[1] Kirtley F. Mather, "Oil and Gas Resources of the Northeastern Part of Sumner County, Tennessee," Bulletin 24, Pt. II B, *Tenn. Geol. Survey* (1920), p. 20.

The big lime, as known by the drillers in Kentucky, is the old Bangor limestone of the early geologists in this section. This 800 feet or more of oolitic and granular limestones is now known to include the Chester formations plus the underlying St. Louis limestone. The oil obtained at Glenmary, Scott County, Tennessee, from a small pool, which has been continuously producing since 1912, is from the St. Louis limestone. There are undoubtedly other areas in the Cumberland Mountain region of Tennessee and Kentucky where this formation may be found to be productive of oil.

In the east Kentucky coal field there are several good oil and gas horizons. The best gas horizon in Kentucky is the Maxton sandstone, a buff-to-white sand 5 to 30 feet thick,[1] which is occasionally split by a shale into two members. This sand has, however, produced considerable oil in Floyd County, Kentucky, and is probably productive in other places. The Maxton sandstone is of Mississippian age, and is probably equivalent to one of the sandstone lentils in the Pennington formation of southern Kentucky and Tennessee. The Maxton sandstone horizon is probably represented in Tennessee, just south of the Kentucky line, by one of the thin sandstones, which is found in the Pennington. A section of the Pennington formation on the Tennessee Central Railroad, between Monterey and Brotherton in Putman County, shows five sandstones ranging in thickness from 5 to 25 feet, occurring in the 270 feet of Pennington shale here exposed.[2]

In the west Kentucky coal field, drilling during 1922 has brought in a number of fine oil wells from the Tar Springs sandstone of the upper part of the Chester group of Mississippian age, in the vicinity of Pellville in Hancock County. Stratigraphically this formation is of approximately the same age as the Maxton sand of the east Kentucky area, as they both belong to the upper part of the Chester group of Mississippian age. In Muhlenburg County, in the southern edge of the west Kentucky coal field, oil and gas have been found

[1] W. R. Jillson, *op. cit.*, p. 12.

[2] Wilbur A. Nelson, "Mineral Products along the Tennessee Central Railroad, Resources of Tennessee," *Tenn. Geol. Survey* (1913), Vol. 3, No. 3, pp. 144–45.

in the upper part of the Chester. The sand at this locality has been named by the Kentucky Geological Survey the "Penrod" sand. To date, this sand appears to be primarily a gas sand.

The fact that oil and gas is being found in paying quantities at several widely separated points near the northeast, northwest, and southern part of the west Kentucky coal field indicates that the sands of the Chester group of Mississippian age are well worth a test in the west Kentucky coal-field area.

PENNSYLVANIAN OIL HORIZONS

Several of the Pottsville sands (lower Pennsylvanian) of the east Kentucky coal field have produced oil in paying quantities, and some of the first production in the state came from these formations.

Of most interest at the present time are the lower Alleghany sands of the west Kentucky coal field, as recently several good wells have been brought in in Union County, Kentucky, from the Sebree sandstone. This formation, which is described by Glenn,[1] forms the top of the Tradewater formation, which is at the base of the Alleghany in the west Kentucky coal field. A few wells drilled in Union, Henderson, and Webster counties, Kentucky, in 1922, have produced oil from this horizon.

GULF EMBAYMENT OIL HORIZONS

Probably of most interest at the present time are the possibilities of finding oil and gas in the Gulf embayment deposits of west Tennessee and of the Purchase region of Kentucky.

West Tennessee remains one of the largest untested areas of the Gulf coastal formations anywhere in the south. It has an area 100 miles long in north and south direction, and 70 miles wide, on average, in an east and west direction, all of which area is underlain by formations of upper Cretaceous age, corresponding to the formations from which oil and gas is being obtained in Arkansas. In this entire area only one well has been drilled down to the Gulf embayment. This well was in the extreme northwest corner of the

[1] L. C. Glenn, "Geology of Webster County," *Kentucky Geol. Survey* (1922), pp. 70–71.

state at Proctor City. In the past five years not over six wells have been started in this area, and all of them, with the exception of the one previously mentioned, were lost before passing into the Cretaceous formations corresponding in age to the Nacatoch sand.

Work done by the Tennessee Geological Survey indicates that there are areas in west Tennessee which large oil companies would be justified in drilling. In particular, surface exposures indicate that there may be favorable structure at points between Somerville, in Fayette County, and Jackson, in Madison County, and also around Reelfoot Lake, in the northwest corner of the state.

THE MINERVA OIL FIELD, MILAM COUNTY, TEXAS

D. S. HAGER AND I. O. BROWN
Houston, Texas

INTRODUCTION

On February 17, 1921, the Okla-Bell Oil Company drilled in the first paying well in the Minerva pool, Milam County, Texas. It was located on the Robert Isaacs farm, 1¼ miles northwest of the town of Minerva, near the central part of the county, on the S.A. & A.P. Railroad. The well came in as an 8-barrel producer; the top of the sand was encountered at 596 feet, and the depth of the hole was 627 feet. The next well to be drilled was the C. F. Neihaus No. 1, which was completed June 5, 1921, for 15 barrels. On August 9, the Okla-Bell Oil Company completed its Ben McClellan No. 1 for 8 barrels. It was not until the early part of 1922, however, that development actively started in the Minerva shallow pool. On November 1, 1923, there were 153 producing oil wells in the pool, 1 gas well, and 18 dry holes. The central part of this field is now located about 1¾ miles southwest of the town of Minerva. The production so far is confined to the T. C. Chambers, A. F. Burchard, and Jose Leal surveys.

TOPOGRAPHY

The Minerva field lies along both sides of Cat Tail Creek, the flat bottoms of which slope down to Little River. To the east of the creek is gently rolling land 20–25 feet higher; to the west is Cat Tail Ridge which rises 20–30 feet above the creek bottoms. The west flank of this ridge extends down to San Gabriel Creek and the surface slope in places coincides with the dip of the underlying rocks.

STRATIGRAPHY

In the Minerva field the strata exposed at the surface consist of yellow and red sand and shales of Wilcox age. Seventy to

eighty logs in the field were studied to determine the thickness of the Midway and Wilcox formations. In the central part of the field the Wilcox is 75–150 feet thick, depending on the location of the well. To the southeast the thickness of the Wilcox increases, as

TABLE I

RECORD OF TEXAS PLAINS NO. 1 NEIHAUS

Depth	Formation
8	Soil
14	Gravel, sand, little water
25	Yellow clay, sand, gravel, considerable water
32	Gumbo
33	Hard lime shell
41	Dark-blue shale, layers of green sand
80	Soft gray shale, light-green sand
98	Dark-blue, hard shale, showing shells
99	Very hard black lime, slight oil show
228	Dark-blue hard shale, sand, few shells
336	Hard dark-blue shale
408	Hard blue shale, gray lime, shells
410	Hard lime shell
475	Hard blue shale, bowlders
489	Rotten black shale
490	Hard gray lime
505	Hard blue shale, bowlders
508	Green sand
515	Hard green shale, thin lime layers, bowlders
518	Light-green shale, some shells
530	Light-gray shale, thin layers lime
531	Hard rock
541	Hard blue shale
542	Hard rock
557	Hard gray shale
558	Hard rock
625	Hard blue shale, thin lime layers
633	Soft rotten shale, shell fragments
635	Shell bed
641	Oil sand
643	Very hard, greenish-gray sand rock, pyrites
646	Dark gummy shale
647	Hard lime shell
649	Oil sand
658	Hard gray sandy shale, thin layers of oil shale (17.5 bbls.)

TABLE I—*Continued*

RECORD OF NEWELL NO. 5 NEIHAUS

Depth	Formation
40	Clay and sand
41	Rock (bowlder)
94	Shale and bowlders
96	Hard rock
118	Sandy shale and bowlders
230	Shale
250	Gumbo
255	Shale
264	Gumbo
300	Hard shale and bowlders
440	Soft shale and bowlders
461	Gumbo
466	Shale
485	Gumbo
491	Shale
512	Gumbo
546	Shale
550	Green sand
608	Gumbo
647	Shale
648	Oil sand
649	Shale and sand
652	Oil sand
665	Shale
668	Hard rock
679	Shale (7 bbls.)

the normal dip of the beds is in that direction. It was not possible from an examination of these well logs to divide the Midway-Wilcox strata definitely. It seems probable that the Midway formation is here about 430–50 feet thick, consisting largely of light- and dark-blue and yellowish-brown shales, with thin beds of concretionary limestone. Beneath this shale body is a bed of green sand 1–10 feet thick, which in places is underlain by green shales 8–26 feet thick. In parts of the field this shale is absent. The glauconite green sand, from examination of well cuttings, has been determined to be basal Midway. It is likely that the thin green shale immediately underlying the sand is also of that age.

The oil sands are 125–30 feet below the top of the basal green sand of the Midway. Between the two sands, logs of wells usually show gray to blue or black shales. These are of Navarro age, the uppermost division of the Cretaceous. The foregoing interval is uniform throughout the field. The oil sands are from 6 to 80 feet thick, with shale breaks between the lenses of sand. In places the sand is hard, in others soft; in general, it is a good, dark sand. On pages 633 and 634 are two well logs taken at random from the field. The first log was carefully kept to show details of beds encountered.

STRUCTURE

On the accompanying map, Figure 1, is shown the structure of the field contoured on the top of the green sand at the base of the Midway (sea-level datum). On the Neihaus and Henry tracts there is a small plunging nose or anticline that first attracts attention. This is a productive part of the field, but the producing wells cross the syncline of the structure to the northwest. It would appear that the feature most controlling production in the Minerva field is a terracing or flattening of the dip of the strata, with irregularities in the contours. The dip becomes steep on the southeast side of the field, the subsurface being checked by the surface dips. To the east of the field there is a noticeable increase of the surface dips, with confusing cross-bedding.

In the northwest corner of the field, between the Kemp Oil Company McClellan No. 1 and the Okla-Bell Oil Company McClellan No. 2, there appears to be a small fault of about 30 feet downthrow to the west. On the Neihaus and Leonard Isaacs tracts, in the southern part of the field, the abrupt widening out of the contours may be due to minor faulting.

Figure 2 shows contours on top of the oil sand in the Navarro formation. A study of these two maps brings out the fact that while minor differences in the contours exist, there is a decided general similarity between the structure of the green sand and that of the oil sand. This is significant, as indicating little unconformity between the Midway and the underlying Cretaceous formations. It has been the writers' observation that at other places in Texas

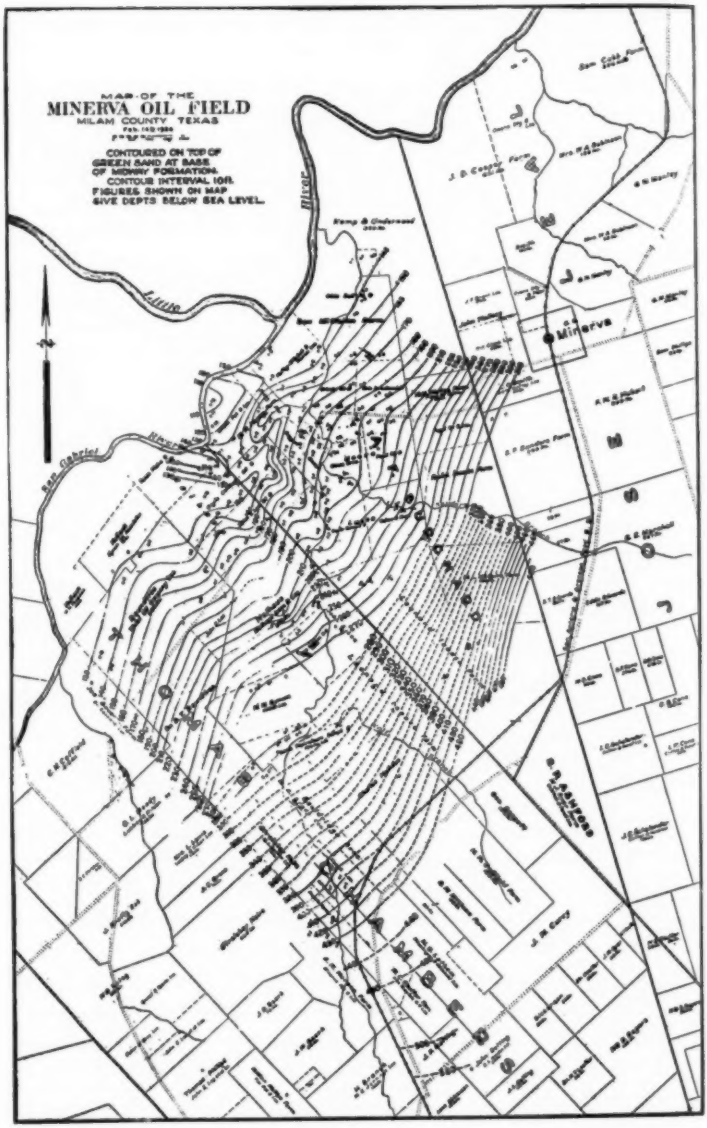
MAP OF THE
MINERVA OIL FIELD
MILAM COUNTY TEXAS
CONTOURED ON TOP OF
GREEN SAND AT BASE
OF MIDWAY FORMATION.
CONTOUR INTERVAL 10Ft.
FIGURES SHOWN ON MAP
GIVE DEPTS BELOW SEA LEVEL.
Little
San Gabriel
Minerva

FIG. 1

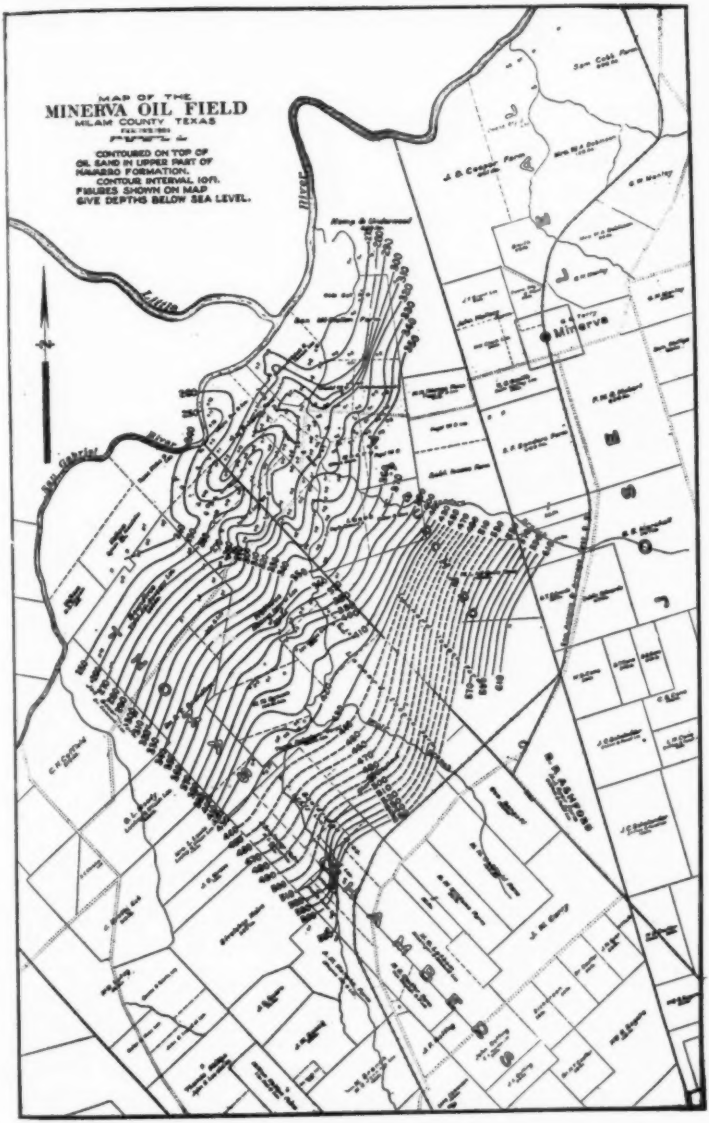
MAP OF THE
MINERVA OIL FIELD
MILAM COUNTY TEXAS
CONTOURED ON TOP OF
OIL SAND IN UPPER PART OF
NACATOCH FORMATION.
CONTOUR INTERVAL 10Ft.
FIGURES SHOWN ON MAP
GIVE DEPTHS BELOW SEA LEVEL.
Minerva
Little
Navasota River
B. B. Simmons

FIG. 2

erosional unconformity does exist between the base of the Eocene and the top of the Cretaceous.

A few surface dips are shown on Figure 1. As a whole, the direction of these dips in the Wilcox is similar to that in the green sand in the Midway. Minor irregularities in the surface dips are usually not shown in the green-sand contours. In the field, however, the surface dips flatten out as do those in the underlying strata; to the east, both become steeper.

DEVELOPMENT

On November 1, 1923, there were 153 producing wells in the field. In the main part of the field the average depth of the wells is 650–75 feet. The depth increases with the normal dip to the southeast, and in the small extension at the extreme south end of the field, on the A. B. Watson and J. Strelsky tracts, the depth of

TABLE II

ANALYSIS OF MINERVA CRUDE OIL

Gravity, at 60° F.	37.7	
Flash-point	Room temperature (70° F.)	
Viscosity, at 70° F.	48″ Saybolt	
Distillation:		
Overpoint, 154° F.		
	Per Cent	
154–268	10.00	
268–328	10.00	Gravity of combined distillates, 50.6 Bé
328–408	10.00	
408–477	10.00	
477–527	6.67	
Residue	51.00	
Distillation loss	2.33	Gravity, 27.4 Be
Gasoline to 302° F.	16.33	59.5 Bé gravity
Gasoline and naphtha to 392° F.	28.33	56.2 Bé gravity
Kerosene, 392 to 527° F.	18.33	42.7 Bé gravity

the wells is about 1,000–1,200 feet. The initial production of the wells varies from 2 to 25 barrels, with an average of about 11 barrels. A few flow, but the rest have to be pumped. Wells which two years ago came in making 20 barrels, within three months were making 10 barrels; six months, 5 barrels; twelve months, 4 barrels; and at the present time are still making $2\frac{1}{2}$ to 3 barrels. Wells which

came in at about 6 barrels dropped within the first six months to $2\frac{1}{2}$ to 3 barrels and held there. In fact, regardless of the initial production, most of the wells get down to about the same figure and stay there. Some of the wells have declined to an output of one-half barrel daily; others have been abandoned.

During the early development of the Minerva pool, the wells were drilled with small spudders, Star machines, rotary and standard

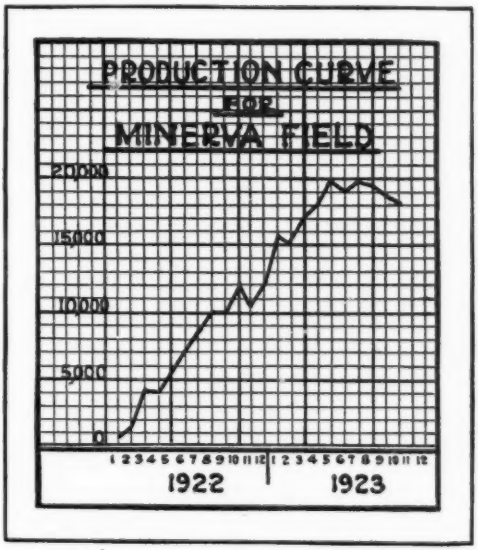

FIG. 3

rigs; the cost to drill, case, and put on the pump was said to be $4.00 per foot. Experience has shown that rotary rigs are the most suitable for the formations encountered, and all the companies in the field, except one, are now using rotaries. The present cost of drilling alone is $1.50 per foot. One joint of surface casing is used, and 650–700 feet or more of 6-inch to $6\frac{5}{8}$-inch are set; it is usually cemented at the bottom. Casing is set to hold up the formations above the sand. Few wells in or around the field have encountered salt water, and where water is present the amount is small.

Up to January, 1924, the Owens Refining Company piped all the oil from the Minerva field to their refinery at Minerva. Recently, Elliot and Blackshear, of Corsicana, Texas, installed a loading rack on the S.A. & A.P. Railroad, and are shipping some of the oil.

On page 638 is an analysis made by E. T. Gregg, of the Gulf Pipe Line Laboratory, Houston, on a sample of crude oil from the Minerva pool, furnished through courtesy of J. H. Edwards, of the Owens Refining Company.

The present daily production for the Minerva field is 565 barrels, or an average of 3.17 barrels per well. On Figure 3 is a production curve for the entire field from January, 1922, to October, 1923. It was furnished by Lloyd North, of the Texas Company, to whom we are also indebted for elevations of wells used in contouring the maps accompanying this paper.

LOGGING WELLS DRILLED BY THE ROTARY METHOD

EDGAR KRAUS
Atlantic Oil Producing Co., Enid, Oklahoma

The most frequent criticism of the rotary method of drilling heard among geologists is that inaccurate logs are supplied when this method of drilling is used. That poor and inaccurate logs often result when wells are drilled by rotary cannot be laid entirely upon the method. It has been the experience of the writer that more often the drillers are responsible for poor or incorrect logs instead of any inherent impossibility of obtaining good logs with the rotary system of drilling.

The instance so often cited to prove the inability of the rotary to give a reliable log, that is, the greater number of recorded changes in formation in a cable-tool well drilled at the side of a rotary drilled well, is hardly conclusive. A similar difference will often result in two rotary holes drilled side by side, in one case by drillers who make an effort to obtain a good log and in the other by drillers whose one aim is to "make hole." It *is* possible to recognize small changes in formation and log them, if the driller's interest in this phase of the work is aroused. It is noteworthy in this connection that the mere presence on a derrick floor of a geologist, or any other person especially interested in formations, during the drilling of a well will result in better logs. The driller's attention is focused by this means on logging and he makes a special effort to identify his formations correctly.

MEASUREMENTS

There is no excuse for inaccuracy as far as measurements are concerned. The depth at which formations are encountered can be kept correctly to within 2 or 3 feet if ordinary care is exercised. The method used by drillers is to keep a record of the drill stem in this fashion: The Kelly joint (about 30 feet long) is first drilled

completely down, and ever after in all measurements and computation is considered to be in the hole—as worded by the drillers: "The Kelly is 'down.'" Then as each fourble of drill pipe (four joints which total about 85 feet in length) is added, it is measured. The exact depth of the hole is then known when each fourble is down, i.e., when the Kelly joint, including all the fourbles, has been entirely put into the hole.

Between the depths at which fourbles are connected the "grayhound" is used. This consists of three lengths of drill pipe, usually with tool-joints on each length, which are successively added to the string of pipe until about 65 feet of hole has been made (the combined length of the total grayhound), after which it is possible to pull out all of the grayhound and add a complete fourble. One joint of the grayhound is styled a single, two a double, and three a thribble. In this way, then, the depth of the hole is accurately known when each joint of the grayhound is down, or about every 21 feet. It is good practice to calibrate the Kelly at 5-foot intervals, or even every foot, starting from the top, using a cold chisel for the purpose. The calibrations should be marked with Roman numerals so that it becomes possible at a glance to determine the depth of the hole at any point by deducting the amount "up" on the Kelly (the amount out of the hole) from the total pipe measurement as computed by the driller for each joint down, which it will be remembered also includes the Kelly.

Steel-line measurements should be taken in addition at important points such as key-horizon markers, possible casing-seats, and above the point an oil sand is expected. This is desirable, because in measuring pipe on the surface no account is taken of the stretch in pipe due to its own weight, and, furthermore, because wind and temperature introduce inaccuracies that are difficult to eliminate entirely. The same steel line should be used each time in taking measurements in the same well to eliminate errors due to differences in steel lines themselves. Lines should be discarded entirely when they have very evidently become stretched.

It is possible, therefore, by the use of steel line and steel tape, correctly and frequently used, to keep measurements correct and so determine *where* formations change. It is the purpose of this

article to describe briefly how the driller recognizes a change in formation, and how he identifies each formation encountered, also to indicate briefly some aids in this recognition other than the core barrel, the use of which has been described elsewhere.

METHOD OF DETERMINING FORMATIONS

First and foremost it may be understood that the driller, with his hand on the brake and familiar with the action of his machinery and pump since the well was "spudded" in, is by far the best judge of the formation in which he is drilling, provided no examination of cuttings and cores is made, in which case, of course, the trained geologist is able to give a better description of the formation than the driller. However, it is possible for a bystander, after a little experience, to gain a very fair idea of formations as they are being drilled through, and it is most desirable that geologists be able to do this. Since they are primarily interested in the logs of wells, they should be able to log a well, or at least check the driller on a well in which they are interested. The action of the pumps, rotary, and engine give the clue to the nature of the formation through which the drill is passing.

Notice the normal speed of the pump and the sound of the exhaust when the drill stem is off bottom. After being on the derrick floor a short time any variation in the sound and speed of the pump is quickly detected. Any slowing of the speed, or laboring of the pump, shows a gumminess or stickiness in the formation. For example, feeding the drill stem as rapidly as it will go while drilling in sand will not affect the speed of the pump. The same tactics in a tough gumbo will stop the pump entirely, and the pressure may even climb so high as to burst connections and drilling hose. All grades of stickiness between these extremes can be noted. In the order of their ability to slow the pump when the drill stem is "crowded," the major formations are arranged as follows: tough gumbo, gumbo or clay, gummy shale, soft shale, sandy shale, hard shale, sand.

The pump is not always immediately affected by a slightly sticky formation, but as the cuttings "ball up" on the bit the pump slows down and the rotary acts as if it were being subjected to

a drag—it takes more steam to keep it rotating at the same speed. To remove this balled-up material the drill stem is "spudded," which is the operation of picking it up 5 or 6 feet, rotating it rapidly and then dropping it until almost on bottom, when it is checked and the weight of the string of pipe gradually allowed to rest upon the bit. This is done several times until the bit is free again. When the drill stem is lifted after being dropped into a sticky formation, it jumps just as the bit pulls out. This is known as "pick-up." In a tough gumbo this jump or pick-up is very great, often causing the pipe to jump 1 or 2 feet and shaking the derrick severely. In less sticky or gummy formation the pick-up is less noticeable, and sometimes can only be detected by feeling the pipe as it is lifted. In sand the pipe lifts without any perceptible pick-up.

In determining the grade of gumminess or clayiness of a formation some mechanical features must be remembered. A short bit will give an added semblance of clayiness because it balls up more easily and because it is easier to plug the water courses in the bit through which the drilling mud circulates. Any other obstruction such as small pipe, or pipe that fits too snugly in the hole or casing and therefore retards the circulation of the drilling mud, will lower the speed of the pump, and must be considered in the determination of formation.

On the other hand, a sudden increase in the speed of the pump does not always indicate a sand. If the pump "runs away" it probably is due to the fact that the mud in the slush pit has become lowered to such an extent that the pump suction has become exposed and the pump does not get a full cylinder of fluid at each stroke, causing it to race. Débris around the suction strainer will produce the same effect. A leak in the connections or a break in the drill pipe will increase the speed of the pump, since the head against which it must pump is reduced in that event.

All such matters are readily noticed and corrected and proper consideration of them is taken by the experienced driller. Once a driller definitely decides that he is in a sand, the practice is to slow down the pump since this saves steam and prevents forcing an excessive amount of fluid into the formation, which would deplete the mud supply.

DETAILS IN THE RECOGNITION OF FORMATIONS

We may enumerate in more detail the characteristics of formations as they are drilled:

Gumbo or clay.—The pump labors. When drill stem is "crowded" it will stop pump. When "spudded," stops pump and has large "pick-up." Bit balls up easily and rotary therefore drags. Tough gumbo drills slowly and must be spudded frequently.

Gummy or sticky shale.—When drill stem is crowded pump labors but will not shut down completely. Bit drags and balls up. When spudded has a pick-up but does not quite stop the pump.

Soft shale.—When drill stem is crowded pump labors a little, but does not ball up badly. When spudded will slow the pump slightly and has a very marked pick-up.

Limy shale.—Pump does not labor but bit balls up when crowded. May or may not slow pump when spudded and has some pick-up.

Sandy shale.—Pump does not labor even when bit is crowded, usually does not ball up (depends upon the amount of sand in the shale—if only a small amount the characteristics will more nearly approach those of shale). When spudded has a slight pick-up. Usually drills very rapidly.

Sand.—Pump will not labor no matter how much bit is crowded. When spudded never slows or stops pump, and has no pick-up. (If bit is badly out of gauge a pick-up may result, but it is easily detected by its dragging nature instead of the sharp pick-up occasioned by a sticky formation.)

Hard shale.—Drills like hard sand and is sometimes mistaken for it. It may, however, slow the pump when bit is crowded very hard; and have a slight pick-up when spudded, in which case it is usually correctly identified.

Hard lime or chalk.—Drills exactly as if the bit were out of gauge, and, therefore, dragging. Balls up on bit to some extent. Hard lime and chalk drill easier with very thin mud than with heavy mud.

Shell.—Drills like sand.

Rock salt.—Drills like soft sand, whitens the mud and leaves a salty crust on the ditch.

Bowlders.—When a *sharp* bit jumps and cuts unevenly, it is usually caused by bowlders of hard material. With a dull bit the same effect can be obtained on any hard formation. This fact accounts for the large amount of bowlders recorded in some rotary well logs. Many of the formations logged as containing bowlders, had they been drilled with sharp bits, would be recorded as hard shale or hard sand. To determine whether or not bowlders are actually present, the bit should be crowded. If it "hangs up," the presence of a bowlder or bowlders is fairly certain. If crowding, on the other hand, seems to do no damage other than the continued jumping of the drill stem, it is probable that the formation is a hard sand or shale. Mechanical obstructions or junk might also give the effect of bowlders.

Gravel.—Drills like coarse sand. The mud returns are either greatly reduced in volume or may even be lost entirely.

Rock.—As recorded by the drillers, rock is any very hard formation other than tough gumbo. The practice of recording rock without distinguishing between sand rock, lime rock, and gypsum cap rock should be discouraged. Even a casual examination of the cuttings will determine the nature of the rock, and further evidence can be obtained by a method to be mentioned below.

When steam is not used for power in running the rig, the pumps are either belt-driven or geared, and some means of judging the character of the formations other than the sound of the exhaust is needed.

On the electrified rig, Watt meters, showing the power consumption of pump and draw-works, very accurately indicate the energy expended in both cutting and pumping a formation. With the further aid of a weight indicator attached to the drilling line, it is possible to keep a certain fixed weight of drill pipe on the bit while drilling. With this factor of weight constant, an increase in the power consumption of the pump indicates that which a laboring pump does when it is steam-driven. The greater the power consumption (for equal conditions of depth, size of pipe, etc.) the greater the stickiness or gumminess of the formation being drilled.

An increased power consumption of the rotary indicates a drag, which on a steam-driven rotary would be reflected by a slowing of the rotary table. The action of spudding and the presence or absence of a pick-up would of course remain unchanged, no matter what the source of power was.

In the gasoline rigs now coming into favor the pump is belt-connected to the prime mover, which operates the rotary as well. On this type of rig more attention must be paid to the action of the rotary than that of the pump, and this is facilitated by the fact that the rig is much quieter in operation than the steam-driven outfit, and, therefore, it is possible to notice smaller differences in the action of the rotary, and small changes in the speed of the gasoline engine. Some idea of what the pump is doing can be gained on this type of rig by having a pressure gauge in the discharge line, at some point where it can readily be seen by the driller. It takes a little time on this type of rig to learn the characteristics of the various formations as they are drilled through, but after some

experience they can be as accurately determined as on other types of rigs.

The other aids in identification, such as action while spudding and aids to be mentioned below, are as applicable to the gasoline rig as to the steam-driven rig. Usually gasoline rigs are used primarily for exploratory work, in which case cores are frequently taken, and cuttings collected, so that identification is not left entirely to the judgment of the driller.

OTHER AIDS IN IDENTIFICATION

Appearance of bit.—Some assistance in determining or confirming identification of the formation that has been drilled through is found in the appearance of the bit when it reaches the surface. A bit that has become dull in sand is worn smooth, the striations on it being very fine, and the surface is bright. Very coarse striations on the bit usually indicate that the formation through which the bit has passed contained pyrite.

Lime in a formation draws the temper of the bit, and causes the edges to turn over. This is very characteristic and will result even if the bit was tempered so as to leave it exceptionally hard. It would seem that the heat due to depth and friction combined with the action of the lime are enough to cause an actual flow of metal as the bit rotates.

Bowlders or junk in the hole will break jagged pieces out of the bit, not, however, to be confused with merely broken points caused by too hard tempering.

Salt wears the bit so that it comes out of the hole with a saw-tooth edge.

Sampling methods.—Besides the methods of identification above noted, which are all in the nature of a diagnosis, based on deductions (mostly unconscious on the driller's part), the more direct method of sampling the formation drilled is used. Three varieties of samples are obtained in usual practice. They are: (1) bit samples, (2) flow samples or cuttings, and (3) core samples.

The bit sample is obtained sometimes by accident, and may be obtained frequently when desired. When a good bit sample is desired, the pump is shut down completely and a foot or so of hole

made. If the hole has been caving or is in bad condition in any way, the pump should not be completely shut down. The drill stem is then pulled in the ordinary way. If the formation is at all sticky, good samples are often obtained in this way, which compare favorably even with core samples, and save the round trip necessary in taking a core. Such a sample should be taken each time it is necessary to come out of the hole to change bits, and will confirm the identification of the last formation drilled. It is even possible at times to obtain samples of fairly sandy formations by this means. The gumbos and shales usually are found sticking to the bit either on its face or under the collar, even when no special effort has been made to obtain a sample.

Flow samples, as the name implies, are collected from the drilling mud as it issues from the well. After casing has been set, a tee is usually put on, and a flow line from it to the side of the derrick arranged to discharge the mud stream into the ditch. This makes it convenient to collect samples in a bucket or a bull plug. If no casing has been set, samples are caught in a bucket placed under the rotary in such a way as to catch part of the mud as it splashes out of the hole. A better method of catching flow samples, but one seldom used, is to build a flow box in the mud ditch itself, arranging baffles in it in such a way that the velocity of the stream is checked and the cuttings so allowed to drop out.

These flow samples when washed clear of the drilling mud yield a good check on the formation being drilled, or rather of the formation that had been drilled when the mud sampled was on bottom. Various systems of collecting flow samples are used. One method is to take samples at specified intervals—usually every 10 feet. For subsurface work this is very satisfactory.

For the identification of formations on the derrick floor it is more advantageous to sample only *changes* in formation. This is done by two methods. By the first method, drilling continues uninterrupted and a sample is caught at an interval of time after the change is suspected, long enough to insure getting the cuttings from below that change. The time interval to accomplish that purpose varies with the depth of hole, size of casing and drill stem, and speed of the pump.

The second method is one that is recommended where accurate results are desired. After a change of formation has been noted, or is suspected, drilling is stopped but the pumps kept running at full speed until all the cuttings have been washed out of the hole. The bull plug or flow box used to collect the cuttings is then carefully sluiced out so that all old cuttings are washed away. Drilling is then resumed. The first cuttings that then appear are the true samples of the formation. This method is very seldom used because it has one great disadvantage. The time required to pump all the old cuttings out of the hole may be considerable, forty-five to sixty minutes often in deep holes. During this time no drilling is done—an item of importance when speedy work is desired. But this method will often determine for a driller whether he is in hard shale or hard sand, which knowledge will save two round trips in coring, which takes much more time. It has the great advantage of delivering cuttings almost entirely free from cavings, and gives a sample that may definitely be stated to come from a certain depth—the depth at which drilling was resumed after the interval of pumping.

Since coring has been excellently described elsewhere, and the various types of core barrels often illustrated, there is no need to enter into a detailed discussion of that method of sampling.

Cores should be taken in all sands and sandy shales when wildcatting, and often it is not amiss to take more than one core in a formation even if the first core shows no oil. It is the usual practice to take a core in a wildcat well whenever the sand or suspected sand has been penetrated far enough to be certain an actual change has occurred. This may be from 6 inches to 3 feet into the formation. Even if the formation is an oil sand, it is possible for the first core to show little or no oil, since it would have been taken in the portion of the sand where gas had most probably displaced the oil. For this reason, it is desirable to take a second core if the formation has sufficient thickness to warrant it.

When a formation is cored and found to contain oil, it should then be cored either with a double-core barrel, which allows a long continuous core to be taken, or should be cored at intervals of from 3 to 5 feet, with the ordinary toothed barrel. By this method more intelligent screen setting can be made and drilling halted before

salt-water horizons have been drilled into too deeply. It might be observed in passing that the core of an oil sand is a far more accurate sample than the cuttings of an oil sand bailed from a well drilled by standard tools.

SUMMARY

Since it is cheaper to drill wells by the rotary method, that system is the most desirable wherever it can be used. By its use many feet of casing can be saved, and drilling time shortened. The only objection to its use, that of the poor resulting records and the possibility of "passing up" an oil sand and mudding it off, is not valid, for, as noted above, an accurate record *can* be kept, and by intelligent use of sampling and coring methods the possibility of missing an oil sand is practically nil. The added cost of careful coring still does not bring the cost of rotary-drilled wells up to that of cable-tool wells, because of the great saving in casing.

GEOLOGICAL ORGANIZATION OF AN OIL COMPANY

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The character of activities as well as size of an oil-company geological department should depend upon the size and scope of operations of the company itself. For example, an oil company might be so well blessed with prospective oil land that the exploration work of the geological organization might be of very minor importance or missing entirely. The company might be chiefly a purchaser of oil, in which case the scouting work might be the most important activity of the geological organization. Many small oil companies retain no geological assistance, depending upon the geological advice of their neighbors.

In the following discussion it will be assumed that we are concerned with the geological department of a large company, the activities of which are broad in scope; that it is a purchaser of prospective as well as proved oil land, and a purchaser as well as a producer of oil.

In order that a geological department shall function successfully it is necessary that it be directed by a single head who is responsible to the executive of the company for the proper organization and the accomplishment of results. It is assumed, of course, that the executive has confidence in the chief geologist, and while exacting of him and his department loyal service and successful work, the geologist should not be hampered in the full exercise of the best scientific methods of his profession, and in this work his authority to carry it out should go hand in hand with his responsibility. Likewise, each geologist in charge of a division of the work should have authority equal with his responsibility for carrying on his work.

The geological department of an oil company embraces four major lines of activities indicated as follows:

a) Exploration of pioneer lands both domestic and foreign.

b) Geological work in aid of oil-field development or petroleum engineering.

c) Appraisal of proved lands or producing properties for purchase or tax purposes.

d) Scouting of pioneer or wildcat drilling and other outside development, also of developed fields where the company is not, but may be, interested either to develop or purchase oil.

1. In view of the great activity to acquire oil land and the competition engendered in this activity, it is almost needless to say that the oil company that does not engage in the most active and wisely directed ***geological exploration work*** and acquire extensive new territory for exploitation will find the opportunities to acquire favorable ground rapidly disappearing. The natural result will be a decline in oil production and profit and a curtailment in the life of the company.

The training of the geologist which will enable him successfully to carry on independent oil-exploration work must be thorough and comprehensive. In addition to his university education in geology and allied sciences he should have well-directed and varied field experience in detailed geological surveys. The problems that come before him will include: (1) the survey by broad reconnaissance of uncharted and unclassified lands wherein he has to distinguish the sequence of the formations, determine their age, and recognize formations that may be a source of oil, and then follow up with detailed surveys that will distinguish geology and structure favorable to oil accumulation as well as the position of possible oil-reservoir strata. (2) The detailed surveys of lands already classified, working out and interpreting structures not previously recognized. (3) Detailed investigation of developed and partially developed properties, and estimating their oil reserves. The requirements in this class of work include some of the duties of the development field geologist. The purpose of such investigation is to acquire land, and such lands may be removed from company property, requiring a wide range of research in the particular field.

The man in charge of the exploration division of a geological department must have not only a thorough and varied practice as a geologist but sound judgment as well. Assisting him should be

men of like training and experience, in such number as the requirements of the oil company demand.

2. The functions of the section of the geological department that has to do with ***development work*** are discharged in the field by the development geologist or engineer. Some companies designate these men as resident or field geologists, others as petroleum engineers, but whatever their designation, their duties are identical. (In this discussion, in order to avoid confusion, the position is called "development geologist.") The development geologist has become one of the most important members of the producing organization in some of the larger companies in California.

The executives of these progressive oil companies have come to realize that technical advice of a geological and engineering character is important in drilling oil wells just as sound engineering advice pays in any other series of mechanical operations. The development geologist in most companies does and should occupy an advisory position. The value of the position to the company depends, therefore, on the support given it by the executives. Experience has shown that it pays to support that position.

The duties of the development geologist include all technical work pertaining to the drilling of new wells and the repair of old wells. The work is carried on by an organization, separate and distinct from the exploratory work, of men trained in engineering as well as geology, and who have obtained their experience from work within the oil fields rather than from purely geological duties.

The personnel of this division of a geological organization should be approximately as follows: Geologist in charge, who is an experienced geologist and engineer, with the necessary staff in the general offices, who is in close touch with the producing executive. This man should direct the work of men employed in this group, and act in co-operation with the manager of development. Working directly under him and responsible to him are one or more well-trained resident development geologists in each field or division. These geologists are in turn in close touch with the respective field or division superintendents and the drilling foremen. Technically trained men entering this branch of the work naturally begin as field assistants. It is desirable to have at least one assistant in

each division who is in training for future responsibilities as resident development geologist. Therefore each resident development geologist should be given duties broad enough in scope or area so that it is economical to use an assistant. The personnel includes in addition to the foregoing the necessary draftsmen, clerks, and stenographers.

The work of the resident development geologist in connection with a particular piece of development work begins with making an estimate of the depth at which various strings of casings should be landed, i.e., depth of shut-off, finish, etc. This is the starting-point for making an estimate of cost of the work, which is necessary in some companies in asking for authorization of the expenditure. To do this he must have the data on surrounding wells, his neighbors' as well as those of his own company. These data either he or his assistants have collected. A file of the complete logs and histories of wells, on adjoining properties at least, should always be on file, both in the division offices and general office. He must have made also numerous vertical sections through groups of wells to correlate his data.

The drilling wells should be visited as often as possible by one of the men, at least once a day when approaching the shut-off point and during the time of drilling between shut-off and finish. When cores are taken it is advisable for one of the men to be in the derrick when the core is brought out, to examine it. At times the character of the core will necessitate modifying previous estimates.

The resident development geologist and drilling foremen should confer at least once a day on the progress of the work. A competent engineer will have many helpful suggestions on avoiding or getting out of trouble that he has learned from experience in his own company or from the experience of other companies. This man should always keep up with new methods and tools, particularly methods employed by other operators to accomplish some definite result and the success or failure of those methods.

It is the practice of the Pacific Oil Company to require some member of the resident development geological staff to be present at every cementing job. This is for the purpose of calculating and observing the quantity of fluid introduced following the cement to

put it in place behind the pipe. A field test is also run by this man on a sample of the cement mixture to determine the length of time for initial set. This latter has become a rather important factor since the use of reagents for hastening the setting time has come into vogue. A typical record covering the data required on a cementing job is shown below.

TABLE I

CEMENTING JOB

Well No. 78. Section *25, 31–24. Sunset-Midway* field—Date 9/6/23
Method—*Perkins*
Total *200* sacks of *Santa Cruz Oil Well* cement used
Mixed *100* sacks cement with *70* cu.ft. of water
Mixed *100* sacks cement with *McDuffie's* reagent
Detail of casing: Total *3,593* ft. of *10* in.
981 ft. of *54* lb. *Youngstown* make
2,612 ft. of *45* lb. *Youngstown* make
Shoe *Plain* Guide *Plain* Threads per inch *10*
Factor for *10* in. *54* lb. is *0.5221*. Volume for *981* ft. is *512* cu.ft.
Factor for *10* in. *45* lb. is *0.5411*. Volume for *2,612* ft. is *1,413* cu.ft.
Computed volume *1,925* cu.ft.
Meter reading at start *22,033*. Computed meter reading at finish *23,958*
Mud put in *883* cu.ft. Computed finish less mud *23,075*
Meter reading at finish *23,118* Difference *43 cu. ft. over*
Final gauge pressure *350* lb.
Circumference of mud tank *24.6 ft.*
Volume per tenth foot of depth *4.8* cu.ft.
Number of feet mud put in *18.41*
Began mixing cement at *10:10* A.M. Cement in pipe at *11:52* A.M.
Began pumping water at *11:54* A.M. Finished pumping water at *1:00* P.M.
Depth of hole *3,607* ft. Casing landed at *3,575 ft.* in *shale*
Bail to *1,800* ft. for water test
Remarks: *Used 4 in.×4 in. ×20 ft. Spacer between plugs. Used the Hamer Hood Gland Cement Head.*
Cement mixed by hand.

The advisory work of the resident development geologist is not limited to the drilling of new wells. Through a study of current and past production records and frequent consultations with the production foremen he keeps posted on the condition and productivity of all producing wells on the properties in his territory. If a well goes off production or falls below what it normally should

make, he investigates the conditions of that well and makes a report to the division superintendent, covering the condition of the well and the work necessary to bring it to maximum production. A report of this character can ordinarily be prepared to follow a form such as is shown in the following example. This report forms the basis for preparing an estimate of the cost for the work to be done.

TABLE II

REPORT OF RESIDENT GEOLOGIST ON UNSATISFACTORY WELLS

Field *Coalinga* Date *March 12, 1921*

WELL NO. *212.* SECTION *17, 20–15*

HISTORY TO DATE

Drilled January–April, 1919. Rotary landed and cemented 10" casing at 2,621'. Water shut off. Completed with 8¼ in. at 2,731 ft.

PRESENT CONDITION

Total depth: *2,745 ft.*
Plugs: *None*
Casing record: *15½ in. S.P. casing set at 70*
10 in. 40 & 45 lb. casing set at 2,621—cemented
8¼ in. 36 lb. casing set at 2,731
Sidetracked casing or junk: *None*
Perforations: *8¼ in. perforated 2,589–2,731*
5 rows: ¼ in.×3 in. holes; 8 in. centers—shop slotted
Present production: (*oil*) *34 barrels daily*
Present average production of wells within ¼ m. radius:
49 barrels oil per day
Present production of largest well within ¼ m. radius:
Well 220, 17, 20–15—93 barrels oil daily
Present or recent production of water:
Well 212 produced an average of 108 barrels water daily during February, 1921. Analysis indicates top water.
Water condition in surrounding wells:
No water trouble in wells within ¼ m.
Present condition of casing:
In good condition to bottom.

RECOMMENDATIONS

An analysis of the water produced by this well shows it to be top water. The well is producing 34 barrels of oil a day with 108 barrels of water. Fluid level of 1,470' and production of oil do not show a full head of top water present.

A casing leak is possible and setting of packer would be first thing in order. Cut 8¼ casing at 2,606 and set hemp packer. Put well on beam and pump for 60 days to determine effectiveness of work. If this does not exclude water further recommendations will be made.

During the prosecution of drilling new wells or the repair of old ones it often becomes necessary to carry out a series of systematic tests. For example, a well might be drilled to completion and upon attempting to produce it, it proves to be a water well or possibly the well under treatment may be an old well that has "gone to water." In either case a series of tests may be necessary to determine the source of the water. Usually these tests are carried on under the supervision of the field development geologist who has first submitted an outline of the work to be done to his chief for approval. Some of these tests require considerable mechanical ingenuity. The data from the test work as it proceeds should be carefully recorded and analyzed in order that correct conclusions may be drawn.

The drillers' reports should pass under the scrutiny of the development geologist daily. It is constantly necessary to correct or amplify these reports so that full and correct data on the wells are available in the files when future work on these wells becomes necessary.

The California state laws require that various and sundry notices be filed with the Department of Petroleum and Gas before and during the progress of any work on wells. These notices can best be handled through the office of the resident development geologist, for the information contained on the notices is merely a copy of part of the data he has already prepared.

The field office of the development geologist is a clearing-house for all information on the physical condition of wells. To this office come both members of his own organization and those from other organizations for information on wells. Consequently, it is necessary that this office find lodgment for all such information.

The development geologist in California has assumed, through force of circumstances, the position of the mining engineer in the mining industry. As improvement in methods of operation demanded more and more use of technical advice, the natural

place to turn for such advice was to the geologist, for often he was the only man in the field organization who had the necessary technical training and who at the same time was familiar with drilling methods and procedure. This change of activities from the former simple service of figuring shut-off and finish depths—which were often ignored—has come about gradually. It is probably as well that the change should have been gradual, for as a new duty was added the management had the opportunity to note the effectiveness of the work, before adding others. As a consequence, the work is now well established on a firm foundation in a number of companies.

Supplemental to the field organization in development work is the analytical chemist. For a number of years, in California much benefit has been derived from the analysis of certain well waters. The analysis of these waters has been an aid in determining their position and thus simplified the repair work necessary to exclude them when encountered. Such a chemist should be a member of the geological department, for he must work in close co-operation with the development geologist who will necessarily have to interpret the results of the analysis. Any water analysis must be interpreted with the physical conditions in the well, at the time the water sample was taken, constantly in mind. The analytical chemist is ordinarily not sufficiently familiar with drilling operations to do this.

The use of paleontology as an adjunct of development work in the past has been limited and of only minor service for the reason that only occasionally could determinable fossils be obtained from the drillings. More recently great impetus has been given this class of work by the collection and study of micro-organisms brought up in sediment on the bit and in cores. In California oil-bearing formations these organisms are extremely abundant and through them and other fossils we are able to classify concealed formations and detect definite zones and horizons. Thus we are becoming better able to correlate oil- and water-bearing strata and to anticipate the position of new oil-bearing zones.

3. *Appraisal work.*—Where an oil company is expanding its operations through purchases of proved oil land or producing proper-

ties the present worth of such properties is often desired, and it has become a custom in California to have an engineering appraisal made. Furthermore, since the adoption by the United States Treasury Department of the unit-value method for the determination of depletion deductions in connection with federal income taxes, and since the income tax law has permitted the claiming of discoveries in the same connection, a large amount of appraisal work for tax purposes has also become necessary.

Certain fundamental principles are employed in any appraisal, and the only inherent difference between the two appraisals just mentioned is the character and amount of information available. In tax work one is dealing with his own company's properties and generally has some control over the collection of data to be used, hence there is ordinarily available much more accurate and complete data than is obtainable regarding a property to be appraised for purchase.

The necessary data in the latter case ordinarily must be ferreted out of whatever records are available by someone in the geological organization, as an assigned problem.

While in the past a large part of the tax work has been done by independent engineers and geologists, the larger companies in California now carry on this work with their own organization. With most of these companies it is handled by the geological department, and rightfully so, for an appraisal is after all primarily a detailed study of the subsurface conditions surrounding the recovery of oil from a given tract.

Quite properly tax work is assigned to the head development geologist, who, it is assumed, has reached that position through training and experience along both geological and engineering lines. Under ordinary circumstances he will have had experience in both exploration and development work, though naturally the preponderance of training will have been in the latter. There is a certain personal-equation factor in all appraisal work calling for sound judgment. The proper foundation for such judgment is obtained through the training he has had.

In his office staff there should be one or more geologists who are valuation engineers competent to handle this sort of work. These

men should be well versed in field-operating methods, should have a fairly wide knowledge of subsurface conditions in the various fields, and should know something about the principles of accounting.

The field organization working under the direction of the development geologist forms an excellent agency for collection of pertinent data on the property under examination, for it is familiar with the physical as well as geological conditions within a given area.

It is necessary, in order to carry on this character of work systematically, for the development geologist to have in his files the logs of a large number of wells for use in subsurface studies, as extensive production records as possible, available for use in the construction of curves, and complete cost data on his own company's operations. These cost data not only form the basis of intelligent estimates of future costs on his own properties but act as a guide or measuring stick to compare with reported costs on other properties.

With such records as mentioned above, together with the additional data on the particular piece of property under consideration, a comprehensive appraisal can be made in a relatively short time.

4. ***Scouting*** is one of the most important activities of an oil company's geological organization. In the earlier experience in the California oil fields the scout was a man perhaps with limited education and training who could collect well-drilling and production data and locate new wells. Now it is recognized that the requirements of a scout are that he shall have the training of a development geologist and, in addition, if possible, experience in detailed exploration. His duties include all fields outside those in which his company is carrying on development besides all outlying pioneer or wildcat drilling.

Should he be detailed in a developed field where his company is not engaged his work is essentially that of a development geologist, collecting all information on drilling and production, with the exception that he is not adviser in that field to any production company unless his advice is solicited. His duties require that he shall always be diplomatic, exchanging any information that he may have that is not confidential for favors received. In case his

company is a contract purchaser of oil from production companies in his field, it will be his privilege and duty to obtain all possible data on their wells and be able from time to time to report upon actual conditions of producing wells and to make forecasts as to their future production.

The scout in wildcat territory has varied and important duties —from those of the development geologist, when he gathers all data on the drilling wells, to those of the exploration geologist; for it is his duty to survey the prospective field sought to be developed by the wildcat well and to report to his company upon the geology of that locality. Thus, the scout is in fact a pioneer geologist, and may be able to designate lands that will make new oil fields for his company.

THE ORIGIN OF THE GREEN RIVER FORMATION

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No scientific problem is settled until it is settled correctly and in accordance with all the facts. A decision based upon preponderance of evidence, the method necessarily recognized in courts of justice, is not satisfactory in scientific investigation, for a conclusion contradicted by any definite, indisputable fact is not acceptable. An apparent contradictory fact, even though it may seem insignificant as compared with other facts, must be either disproved or explained in harmony with one's conclusion before it may properly be considered final.

With this academic sermonette in mind, let us approach the problem of the origin of the Green River shales, the solution of which problem may have far-reaching effect upon theories of the origin and accumulation of petroleum. There are strong reasons for believing that the oil of this formation is not migratory, and, so far as the writer knows, no reason for believing that it is. Is it an exception to the general rule that formations containing oil in great quantities are marine or saline, or closely associated with saline formations? Is the origin of shale oil, obtainable by distillation processes, different from that of oil existing in a free state and obtainable by ordinary methods of drilling and pumping, or flowing at the surface when the formation is pierced by the drill? If not, and if the formation is of fresh-water origin, as generally believed, and if the oil is indigenous, not migratory, what becomes of all the discussion of the relation of petroleum to marine conditions? No evidence has yet been found of marine conditions prevailing during Eocene time within hundreds of miles of the Green River formation.

There is a widespread belief among geologists that in some way saline waters, not necessarily marine, but usually so, are connected with and necessary to the origin of petroleum in large quantities.

The fact that sediments settle more rapidly in saline than in fresh water, dragging down with them and burying great quantities of minute life, thus trapping before they may be dissipated the hydrocarbons from which oil may later be distilled by natural processes; the possible effects of bacteria, aerobic or anaerobic, in the decomposition of organic material, and various other questions under discussion by geologists, revolve about the question whether the origin or accumulation of petroleum is necessarily connected with or dependent upon saline conditions. If a thick and extensive formation containing vast quantities of oil is a fresh-water deposit, it may radically change the trend of thought concerning the origin of petroleum.

The Green River formation of northwestern Colorado, northeastern Utah, southwestern Wyoming, and southeastern Idaho, extending over an area of hundreds of square miles and hundreds of feet in thickness, contains one of the most notable deposits of shale oil, yet it seems to be universally considered a fresh-water lake deposit. The weight of evidence certainly favors that theory, but may not be entirely conclusive.

The fine-grained, thin-bedded sediments of such great thickness extending over so large an area, far from any known marine deposits, strongly suggest deposition in a great lake of some sort. The only alternative seems to be deposition by meandering streams, with shallow, temporary, shifting lakes. It is difficult to see how it could have been so deposited, or, if so, how such great quantities of oil could have been trapped in the process. Cross-bedding, ripple marks, drying-cracks and other phenomena such as would characterize deposition under those conditions are either very rare or absent throughout most of the formation. On the other hand, certain phenomena are difficult to explain under the lake hypothesis, such, for example, as the distribution of non-aquatic insect larvae. Even with such fine material, should there not be very marked thinning from the edges inward, particularly at distances 10 miles or more from the shore?

If it is a lake formation, whether saline or fresh-water is a very important question. It may have been alternately saline and fresh, as was ancient Lake Bonneville. By saline one does not necessarily

mean marine. It may have been only strongly brackish water, or the salts may not have been sodium chloride.

The fossils of the formation, though abundant and of many species, are mostly non-aquatic, and throw very little light upon the origin of the formation. A more thorough study of the microscopic flora and of the insect fauna, by those competent to handle such subjects, with these problems in mind and a thorough understanding of the importance of correct conclusions, may in the future produce results. The essential paleontological and paleobotanical data have been summarized by Winchester[1] and Knowlton.[2] The fossil fishes and their significance have also been discussed by Cope[3] and Osburn.[4]

Thirty-five species of fishes are recognized from the shales, of which 22.8 per cent, including three families, with four genera and eight species, have pronounced marine affiliations, a large proportion for a fresh-water fauna. Of herrings there are three genera, with six species. The herrings now living are mainly marine, though some ascend the rivers to spawn and a few live in fresh-water. The sting-rays, represented in this fauna by a clearly defined species, are mostly marine, though a few live in fresh or brackish waters. Osborn says that the genus *Notogoneus* belongs to a family (Gonorhynchidae), the living members of which are all strictly marine. The peculiar scales certainly do appear to indicate rather clearly that the genus is in or at least closely related to the Gonorhychidae, but the latter are toothed fishes, while *Notogoneus* is not. Hence the relationship may not be as close as is supposed, and even if so, it does not prove that this genus is marine, as exceptions are known in other families and may also occur in this. The relationship, though suggestive, proves nothing as to the character of the water in which the fishes lived. With this possible exception, no exclusively marine type is found, so the fish fauna as a whole is consistent with the idea that at the time they lived fresh-water conditions prevailed in the localities where they are found. However, the fine fish skeletons for which the formation is famous have been found almost exclusively

[1] *U. S. G. S.*, Bull. 729, 1923.

[2] *Ibid.*, Prof. Paper, 131 (1923), pp. 133–82.

[3] *Ann. Rept. Hayden Surv. for 1870*, p. 431.

[4] *Age of Mammals* (1910), p. 136.

in a thin stratum within a comparatively small area in western Wyoming, with a few in northwestern Colorado. Throughout much the greater part of the extent of the formation and through nearly its whole thickness fish bones and scales are rather rare and skeletons wholly absent. During the past two summers the University of Colorado has had expeditions in northwestern Colorado for the sole purpose of collecting fossils, and, though large quantities of fossil material were found, the fish bones and scales, both teleost and ganoid, were negligible and no skeletons were found. A few dead fishes would be expected to drift far out into the lake before sinking, which would account for the scattered bones and scales occasionally found. The locality where the abundant fine skeletons are found may have been not a great distance from the mouth of a large river, where the water would be comparatively fresh, even though the lake as a whole were saline.

The occurrence of so many skeletons in a thin stratum at Fossil, Wyoming, and Fish Cut, near Green River, is difficult to explain unless an arm of the lake was temporarily cut off and desiccated. If it were a fluviatile deposit, such an accumulation of skeletons could easily occur from the cutting of the necks of ox-bows and silting up both ends, a thing which frequently occurs in the Mississippi Valley, trapping fishes in large numbers. Cope mentions two small schools of herring fry "which must have been taken unawares, since they lie with their heads all in one direction as they swam in close bodies." Under what circumstances could such a thing happen far out in a great lake?

Vertebrate remains other than fishes consist of only a few bird feathers of no geological significance. Fresh-water mollusk shells are reported in one or two places in Utah by Winchester,[1] but are certainly not generally distributed. The writer has found them only at Horsethief Mountain, near DeBeque, close to the base of the formation, and quite likely not far from the edge of the lake during its early history—possibly carried in by streams. They are of little value in solving our problem, but are undoubtedly fresh-water forms.

The macroscopic flora of the formation is extensive and varied. Knowlton recognizes eighty-one species, chiefly leaves of land plants,

[1] *U. S. G. S.*, Bull. 729, p. 32.

some lowland, others upland, including oaks, walnuts, willows, maples, and the like. Branches, logs, and stumps seem to be scarce or absent. The leaves are abundant nearly everywhere in beds well up in the formation, thousands of the best examples being found many miles from any possible shore, assuming the edges of the formation as at present to represent approximately the shoreline. Many of them are too perfect for one to suppose they had been transported many miles by streams, waves, or lake currents. If the formation is a vast lake deposit, the trees could not have grown anywhere near the present location of most of the leaves. The most reasonable supposition is that, if it is a lake deposit, they were carried out over the lake and dropped by windstorms. They tell us nothing as to the freshness or salinity of the water. The few aquatic plants, except perhaps the algae, may have been carried to their present positions by known agencies. One can scarcely believe that the reeds grew in the middle of a lake larger than the state of Rhode Island.

The microscopic flora has been discussed briefly by both Winchester and Knowlton. It consists of conifer pollen, moss spores, annuli from fern sporangia, and bark fragments, which surely must have been all or nearly all blown or drifted from the land, perhaps many miles away; molds, which may have been carried out on the leaves of fragments of land plants with which they are associated; bacteria, which may be found in both fresh and saline water; blue-green algae, which, according to botanical friends, occur in both fresh and brackish water, but not in marine water; *Spirogyra* and *Protococcus*, which are supposedly fresh-water organisms. It is these low organisms, especially the algae, which are believed to have furnished a large part of the hydrocarbons constituting the shale oil. The reported abundance of the algae, especially if it refers to the strictly fresh-water types, is the only real evidence bearing upon the question of the character of the water in which the shales were deposited. While the natural inference is that the algae grew in the water where they are now found, it must not be forgotten that there is a large admixture of material which simply could not have grown under like conditions, which raises the question, Is it all transported material?

Professor Cockerell[1] lists about 275 species of insects and 2 or 3 myriapods and spiders from the Green River shales. They are practically all flying insects, which could be carried long distances by air currents and dropped into the water in perfect condition, to sink to the bottom and be buried by the sediments. Indeed, that is just what must have happened to the numerous species which do not breed in the water, if the formation is a lake deposit, and could equally well happen to the adults of those which do breed in streams and fresh-water swamps. The writer has seen dense swarms of mosquitoes many miles from the nearest possible breeding-places, during dry seasons in the arid West. During one season they actually interfered with our work out on the dry ridges in Wyoming. Two or three fossil insects from the Green River shales do not seem so easily disposed of. A caddis larva case has been recorded by Scudder and a dragon-fly larva by Cockerell. They breed in fresh-water and are unable to fly until the adult stage. The significance of their isolated occurrence, however, is completely discounted by the fact that far the most abundant and widely distributed fossil over the whole of the large area which the writer has examined is considered by eminent entomologists to be a botfly larva. At every station we found it by thousands. The stratum containing the larvae appeared to be continuous from station to station, though we did not actually trace it through. We also have the same thing from far-distant localities in the formation, in equal abundance. Botflies are not aquatic at any stage of their existence. The larvae of living species infest land mammals, those parasitic in sheep, cattle, and horses being especially well known. These larvae must be accounted for in determining the origin of this formation. If they could be distributed in such abundance over such a large area, one or two caddis cases and a dragon-fly larva need not disturb us at all. All attempts to account for them have thus far been in vain. It is difficult to conceive conditions under which they could be so distributed in such abundance, particularly in a lacustrine formation. An entomological friend, with grave countenance but a merry twinkle in his eye, has suggested that "they are an invention of the devil to deceive and confuse mankind."

[1] "Winchester's Bulletin," *U. S. G. S.*, 729, pp. 22–30.

This is not a constructive paper; neither is it intended to be destructive. It is intended to be suggestive of further work upon an important problem, and serves its purpose if it creates an interest in the subject, provokes discussion and investigation, and keeps our minds open for new facts and new interpretations of facts already known, for only thus may the problem be ultimately solved to the satisfaction of everybody.

DISCUSSION

C. S. SCHUCHERT: The speaker has long been interested in the fossils of the Green River shales, and in 1919 raised the question whether the oil shales of the Green River formation had not been laid down in somewhat saline waters. President Ball (1922) also spoke of the varied stratigraphic nature of these shales. Now Henderson brings together what is known about the organisms of the shales in question, and from what David White has just said it is very evident that a great deal of very much needed evidence, both physical and organic, is yet to be had in the field and is not yet in the printed record. In fact, White's account of the Green River shales, to which we have just listened, is the best ever presented. It now appears that the climatic factor may be of most importance in explaining the great amount of kerogen in these shales. White thinks of semiaridity under a warm climate, but as no red strata are connected with the shales, I want to ask, may the climate have been cool to cold semiarid, rather than warm? It is under cool conditions that the hydrocarbons of organic origin are most easily preserved, when of a semiarid environment; with warm conditions they are apt to be oxidized, leaving behind some or none of the carbon. Blackwelder and Sayles (1922), because of the banded nature of the Green River shales, have also suggested cool to cold seasonal deposition. The discovery of early Eocene tillites in Colorado by Atwood (1913) may likewise bear on this problem.

GEOLOGICAL NOTES

NOTE ON THE ORIGIN OF PETROLEUM

Of interest in connection with problems of the origin and migration of oil is the accompanying photograph (Fig. 1), which shows a fragment of calcareous material containing several casts of ammonite shells (*Perisphinctus* sp. ?). In some of the spaces which represent the chambers of the original shell (see lower part of figure, at right), are fillings of a solid, glossy-black, brittle petroleum compound which closely

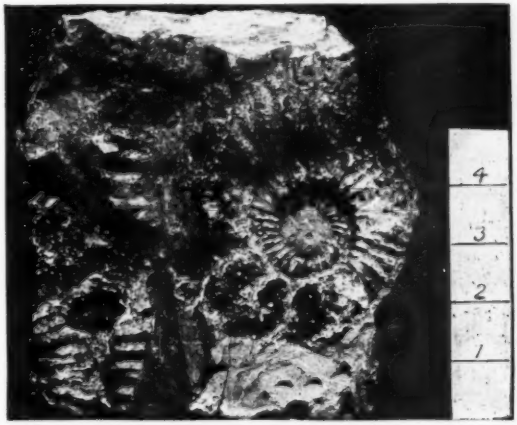

FIG. 1.—Fragment of a calcareous concretion with ammonite shells containing solid petroleum. Scale is in centimeters.

resembles hardened asphalt. It has not yet been analyzed but is probably related to the petroleum group of substances which include rafaelite, grahamite, etc.

The rock specimen photographed was collected by the writer from an exposure of "oil shale" on the east side of the Andes Range, in Mendoza province, Argentina. This shale formation, which we have called the "ammonite shale," carries not only a great many remains of ammonite shells, but also a wealth of impressions and casts of pelecypods, chiefly

of small and delicate species. No plant remains were discovered. These fossils prove the formation to be of Upper Jurassic (Portland) age. It is several hundred feet thick, a dark-gray to black, strongly petroliferous shale, becoming more limy toward its upper portion where it passes into a series of alternating thin-bedded bituminous limestones and shales. Fragments of the shale will burn if first ignited by some more easily combustible substance. Especially in its middle and upper parts, this shale contains numerous very hard, smooth, oval, calcareous concretions

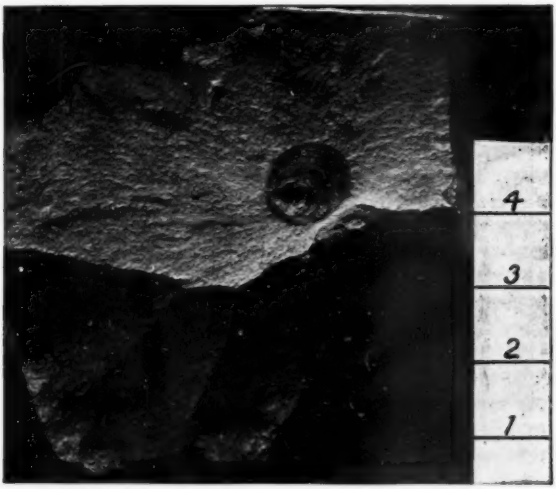

FIG. 2.—Cast of a shell of Discina, very common in the "ammonite shale" and often coated with a thin oily film. Scale is in centimeters.

which, when broken open, are seen to inclose fossil remains of the same kinds and irregularly distributed in the same manner as in the surrounding softer shale.

Many of the ammonite shells have their chambers partly or wholly filled with calcite. Some of them, principally in the concretions, but also occasionally in the shaly matrix, contain a little petroleum, either as a mere stain or in the form of partial or complete fillings of the spaces left unfilled by the calcite (as in the photographed specimen). Glistening petroleum films are common on the outer surfaces of these and other shells, and especially on the small round imprints of a species of Discina, very abundant in some horizons in the formation (Fig. 2).

The ammonite shale is simply one formation within a great group of formations which contain sandstone, gypsum, shale, and limestone, the whole series totaling several thousand feet in thickness. These strata are rather strongly folded. Dips range up to 90°, but are generally between 20° and 60°. At certain localities where the ammonite shale is below the surface (i.e., not eroded away) live seepages of asphalt and veins, or more properly *dikes*, of rafaelite, are known to be present. These are always associated with faults or fracture zones, but never with simple, unbroken exposures of sandstone. In fact, sandstone beds stratigraphically near the shale, and structurally in an attitude favorable for the reception of oil, if any such migrated widely in the region, are free from evidences of having ever contained petroleum. The only exceptions to this statement are the very localized zones adjacent to live seepages, or near the rafaelite "dikes," which are dead seepages.

From all these facts we have drawn the following conclusions:

1. The ammonite shale (including its limy facies) is the principal source rock from which the oil seepages and rafaelite veins in this district have been derived, for (*a*) it is the only highly petroliferous formation in the region,[1] and (*b*) the seepages and rafaelite veins occur only in the area underlain by this shale, being absent where it has been removed by erosion.

2. The petroleum has originated within the ammonite shale, if not generally throughout the rock at least locally in or beside fossil shells and impressions.

3. In this particular formation, petroleum has formed from animal remains.

4. Although petroleum has thus originated, probably under conditions of moderate heat and pressure, it has migrated only where the source rock has been fractured, either by faulting or by intrusion of igneous material with the attendant breaking of the surrounding country rock, thus providing channels for such migration.

5. Possibly the heat and pressure accompanying faulting and volcanic intrusion facilitated the local development of this petroleum.

FREDERIC H. LAHEE

SUN OIL COMPANY
DALLAS, TEX.
May 1, 1924

[1] Possibly other shales and limestone beds within the Jurassic, and not far stratigraphically from the ammonite shale, have supplied some petroleum, but if so their characteristics are similar to those of the ammonite shale. The fact is that in our hasty correlation work we could not be certain whether there was one or more than one "oil shale" in this stratigraphic prism.

USE OF THE SKETCHING CASE IN GEOLOGIC WORK

Numerous articles have appeared in the technical journals on the use of the plane table in geologic work; but the writer has found very little published concerning similar use of the sketching case. The following notes may therefore be of interest to those who have occasion to employ such an instrument, in areas or for work to which the plane table is not well adapted.

Sketching cases of the Batson pattern were used by the writer and his associates in mapping geologically and topographically about 1,100 square miles in Trinidad, British West Indies. The instruments first used

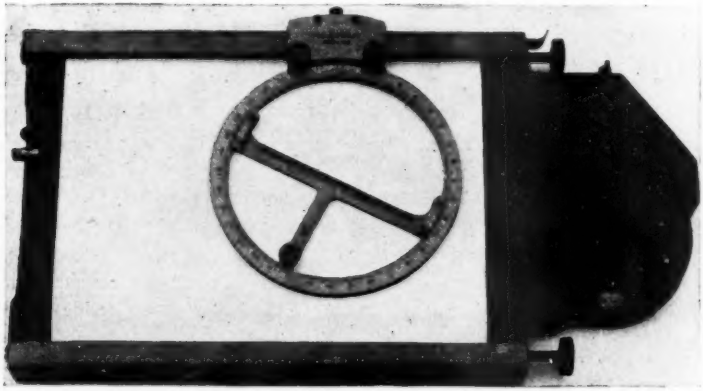

FIG. 1

were of the regular Batson model, formerly manufactured by W. and L. E. Gurley; and later a slightly modified form, as shown in Figure 1, was employed. This will take a sheet 8 inches in width and 4 feet in length of celluloid (and longer of paper), instead of the 6-inch width of the regular model; and the fittings are of brass instead of aluminum, as the latter metal corroded rapidly in the tropical climate. A carrying case of canvas was found preferable to a leather one, as the latter mildewed and increased the corrosion of the instrument.

The method of using the instrument is fairly evident from its construction as it is essentially a light plane table, to be carried on the left forearm. For security it is fitted with a wrist strap on the back. The compass is of the floating-dial type, with thumb release, and is graduated to read

azimuth. The circle, also graduated to read azimuth, carries a straight edge that revolves as a diameter and corresponds to the edge of a plane-table alidade. In plotting a direction the straight edge is set to azimuth corresponding to that of the compass sight taken. Declination is set off by clamping the circle in the proper position.

The rolls on which the "plane-table sheet" winds give movement in two opposite directions, and the sliding of the circle along its bar gives movement in the two directions at right angles to the former. By proper orientation of the circle, any direction on the sheet can be made to correspond to north; and this allows traverses of fairly constant direction to be plotted lengthwise of the sheet. In plotting a sight it is not necessary to bring the middle point of the alidade (center of the circle) to the point representing the station occupied. The alidade can usually be brought into position simply by setting it to the proper azimuth and sliding the circle until the alidade meets the point on the sheet, from which the sight is to be drawn, slightly turning one of the rolls if adjustment along the sheet is needed.

In the Trinidad work the area mapped was mainly forested and the instrument was used almost entirely for running traverses, since there were few opportunities for triangulation, but it is of course as adaptable to the latter kind of work as to the former. Most of the work was done on the scale of 800 feet to the inch, with contour interval of 25 feet, using aneroid for determination of elevation, with the sea coast as datum and the low-gradient courses of the principal streams as checks on the elevations inland. Distances were measured by pacing, and drawn directly to proper length by a scale on the alidade, graduated to fit the person using the instrument, in intervals of ten double paces or ten "counts," counting every fourth step or every other time the left foot came to the ground. This rhythm is easily acquired and is much less fatiguing than counting steps or paces.

The arrangement of circle and alidade above the sheet was found to be much preferable to the type of circle, used below the sheet, on the Army Sketching Case. This latter type of instrument proved unsatisfactory because it requires a translucent paper or celluloid, and the graduations on the circle soon become nearly illegible as they are worn and scratched by the movement of the sheet over it. Also, in the dim light within dense forest it was found very difficult to read the graduations through the sheet.

Established points for horizontal control were available in most parts of the area surveyed, at intervals of ½ to 2 miles; such as Forest

Reserve boundaries and other property lines, triangulation stations, and road and trail junctions. Although in making tortuous traverses, such as along stream courses, the errors in distance in checking in on known points were occasionally as great as 10 per cent, in most of the work the errors were only 4 to 6 per cent, even when pacing over fairly rough country. In areas where approximately parallel traverses 800 to 1,200 feet apart, were run between known lines, the ends of the traverses often checked within 2 per cent of the correct positions.

Errors in direction were usually less than in distance. The method of taking direction by call had to be employed in most of the work, and it was seldom feasible to read azimuth closer than within 3°; but the shots were necessarily short, about 100 yards being the limit of distinct hearing in the dense forest, and the errors in direction of individual shots became compensating in the traverse. In places where direct sights could be taken, azimuth was read to the nearest degree.

Instead of sending a man ahead to call, some of the geologists found it preferable to go ahead with the man who was cutting the way, and take "back-calls" on a man left at the station last occupied. By this method rock outcrops, ridge tops, and turning-points on the traverse and other stations of interest could be selected by the geologist; and also advantageous positions from which to sight on the call of the rear man could be selected. A slight ridge or mound between the instrument man and the rear man often caused indefiniteness in the direction from which the call seemed to come.

In such an area as Trinidad, where neither in the cultivated lands of sugar cane and cocoa, nor in the forests, is the plane table suitable for mapping because of the very short sights that must be taken, the writer believes that the sketching case is a very satisfactory substitute, especially if a fairly large number of known points are available for horizontal control. He would be glad to hear from others who have had occasion to use this type of instrument.

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SANDSTONE INCLUSION IN SALT IN MINE ON AVERY'S ISLAND[1]

On the field trip that included a visit to the salt mine on Avery's Island, Louisiana, following the Houston meeting of the American Association of Petroleum Geologists, a great many samples of the sandstone inclu-

[1] Published by permission of the Director, U. S. Geological Survey.

sion in the salt were collected, and the various collectors advanced strongly contrasting opinions regarding the constitution and origin of this inclusion. It therefore seems worth while to reprint the very careful statement made by G. S. Rogers about this same inclusion.

The only foreign substance yet encountered in the salt is a small slender mass of tough red sandstone in the Avery mine. The mass stands almost vertical and extends at least from the roof of the chamber to the floor, a distance of about 80 feet; it strikes about east and west and has been followed for about 75 feet, disappearing at one end but not at the other. It is extremely irregular in width, ranging up to 10 inches in some places and in others pinching out entirely. The rock, though tough, appears to be brecciated and contains many small fissures filled with salt. Under the microscope it is seen to consist chiefly of quartz crystals with a few fairly fresh feldspars. Some of the grains are very well rounded but others are highly angular. Most of the quartz grains show evidence of strain and there has been considerable secondary enlargement, though hardly enough to warrant classifying the rock as a quartzite. The cement seems to be chiefly silica and iron oxide, but there is also an isotropic, yellowish, structureless substance which was not identified.

Advocates of secondary deposition theories might possibly suggest that this sandstone represents sand which had fallen into a vertical fissure and had later been compacted; but the cement and the secondary enlargement of the quartz grains indicate circulation of ferruginous and silicious waters after the sand had become placed, and such waters could not have circulated through the salt mass without dissolving much salt and introducing much foreign material. Probably, therefore, the rock was cemented before it entered the salt mass. Furthermore, the vertical position of the sandstone mass and its irregularity in width—practical discontinuity—suggest that it has been dragged out in pressure, somewhat as an old pegmatite dike is dragged out in a schist or gneiss. It seems safe to assume that it represents a fragment of sandstone picked up by the salt in its upward course, but there appears to be no way of ascertaining the formation from which it was derived. In general appearance it does not resemble a Tertiary rock, while the red color of course suggests a Permian derivation, though little weight can be placed on such criteria.[1]

The facts presented by Mr. Rogers leave no doubt that the rock is actually a sandstone. His argument for believing it to have been brought from below is also convincing, and is supported by the shape of the large mass of sandstone, which is dissimilar to that of any recorded sandstone dike with which the writer is familiar, and by the disconnected fragments of sandstone adjacent to the main inclusion. If these represented fissure fillings they should be thin, platy layers at least roughly parallel

[1] G. S. Rogers, "Intrusive Origin of the Gulf Coast Salt Domes," *Ec. Geol.*, Vol. 13, No. 6 (Sept. 1918), pp. 471–72.

to the large mass, but at least one was an irregular mass that certainly could not be explained by fissure filling. The red color does not necessarily suggest "a Permian derivation," for both outcrop and well-log evidence in northern Texas, Arkansas, and Louisiana show that red may also be significant of the Comanche, or even of basal Upper Cretaceous rocks, and if Triassic rocks are present beneath the Gulf coastal plain, they are presumably at least in part red, but it does suggest a derivation from rocks much older than any reached by the drill on any coastal salt dome.

Further evidence regarding this inclusion should be put on record. Particularly should the mineral composition be definitely determined both by studying thin sections and by disintegrating large samples, identifying the minerals and particularly the heavy minerals, and determining the relative amounts of each mineral. Careful search in the salt mine will also probably discover other inclusions of light-colored sandstone. In fact, a fragment from one such inclusion, collected by David White, is now on hand but has not been studied.

K. C. HEALD

NEW HAVEN, CONN.

LARGE GAS WELL IN JIM HOGG COUNTY, TEXAS

Jim Hogg County is in the Rio Grande Coastal Plain of southwestern Texas. It is separated from the Rio Grande and Mexico by Zapata and Starr counties. The northwest edge of the county borders on the Mirando oil fields (Schott-Mirando City, Aviators, and Mirando Valley pools) of Webb and Zapata counties.

For some years, more particularly for the past two years, there has been considerable wildcat activity in Jim Hogg County. To June, 1924, a total number of twenty wildcats had been completed in the county. The only one of the twenty which achieved favorable results was the Pippen No. 1, Survey 233, about 5 miles southwest of the old Mexican settlement of Randado. In November, 1922, the Pippen test, which was drilled to a total depth of 1,620 feet, succeeded in making a small gas well from a sand at 1,575 feet. The amount of gas was about 500,000 cubic feet, and, while it has been utilized locally for fuel, yet the Pippen No. 1 could only with difficulty be called a commercial well.

On June 24, 1924, the first commercial well in Jim Hogg County was brought in, the Henne-Winch-Fariss No. 1, Martínez, Survey 256, immediately over the line from Zapata County and 3 miles southeast of the Mirando Valley oil field, Zapata County. This wildcat blew in for

52,800,000 cubic feet of dry gas from a depth of 1,944 to 1,960 feet. The total depth of the hole is 1,960 feet. No salt water has yet appeared with the gas, and only a slight show of oil accompanied it. The rock pressure is 635 pounds. The geologic age of cuttings from a similar depth in adjacent tests is the Fayette formation of the Eocene, as determined by a study by Miss Alva Ellisor, paleontologist for the Humble Oil and Refining Company.

Although no oil has yet been found in Jim Hogg County, the completion of such a large gasser will arouse interest in the potentialities of the county, both for gas and oil. The Henne-Winch-Fariss No. 1, Martínez, is located in the Reynosa fault zone, which passes through the western portion of Jim Hogg County, trending southeastward into Starr County. The derrick stands under the brim of the Reynosa escarpment, midway between two high salients which guard the entrance to a deep re-entrant basin. The escarpment in this vicinity is especially high, steep, and rugged, diversified by conspicuous promontories and by deep re-entrants and narrow valleys, which almost merit the name of canyons.

Credit for discovering the Henne-Winch-Fariss gas well belongs to geology—specifically to Mr. Frank R. Campbell, geologist of Laredo, who, some two years ago, was impressed by the possibilities of this part of Jim Hogg County. Four tests were located by Mr. Campbell before the gasser was brought in. These wildcats were all in close proximity to the location of the present gas well. Shows of oil and gas were encountered in all four holes, but they were not properly handled and were all abandoned as failures.

RICHARD A. JONES

LAREDO, TEXAS
July 17, 1924

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[1] Published by permission of Acting Director of the U. S. Geological Survey.

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BERTRAND L. JOHNSON[1]

Dielectric Separation: A New Method for the Treatment of Ores. By H. S. HATFIELD. Pp. 8.

Dielectric Mineral Separation: Notes on Laboratory Work. By Bernard W. Holman and St. J. R. C. Shepherd. Pp. 7, pls. 2. *Bull. Inst. Min. and Met. (Eng.) No. 233,* February, 1924. Copies of each of these publications may be obtained for 1*s.* at the office of the institution, Cleveland House, 225 City Road, London, E.C. 1, England.

The object of this review is merely to draw the attention of those engaged in the separation of minerals from sands for petrographic purposes to a new method

[1] Assisted by Miss L. M. Jones and Miss M. F. McShea.

of separation that may prove of value. The method is based on the fact that, just as in a non-uniform field of magnetic force particles of a higher permeability than the surrounding medium tend to move from the weaker to the stronger part of the field, so in an electric field particles of a higher dielectric constant than the surrounding medium tend to move from the weaker to the stronger part of the electric field. The difficulty hitherto has been that the dielectric constant of air is about 1, while, according to Hatfield, few minerals have a dielectric constant below 4. Consequently, the air will not support an electric field stronger than the dielectric constant of most minerals so that they all tend to be attracted to the point of greatest concentration of the electric field, and separations could be made only on the basis of differential attraction between those of very high (practically infinite) dielectric constant, i.e., good conductors, and those of relatively very low dielectric constant, i.e., practically non-conductors. Such a method of separation is described by T. Crook on pages 370–373 of the first edition (1913) of Hatch and Rastall's textbook of petrology—*The Sedimentary Rocks*. In the method described in the papers here reviewed the electric field is produced in a liquid of greater dielectric constant than one and less than another of two minerals which are to be separated. When the two minerals are immersed in this liquid the one will be repelled and the other attracted by the electric field. Hatfield uses mixtures of kerosene with a dielectric constant about 2, and nitro-benzine with a dielectric constant about 36, to obtain the desired strength of field.

Three different types of apparatus are described for working with different quantities of material. Holman and Shepherd state the advantages of the method as follows:

> The special interest of dielectric mineral separation arises from the facts that its action is positive, the mineral being attracted and the gangue repelled, and that the property on which it depends, apart from conducting substances, varies far more from mineral to mineral than does any other physical property.

Another advantage claimed is that there appears to be no lower limit as regards the fineness of the materials which can be treated, and clays are spoken of as among those to which the method can be applied.

However, it must be noted that separations cannot be made, by this method, between minerals of high conductivity, i.e., high dielectric constant, such as many or most metallic sulphides, metallic oxides, and native metals; that these must in fact be removed before separations between less highly conducting minerals are attempted.

Holman and Shepherd say: "the process cannot at present be said to have passed the laboratory stage, although applicability to laboratory work, and its scientific interest, may be said to have been demonstrated."

MARCUS I. GOLDMAN

U. S. GEOLOGICAL SURVEY

Petróleos y Minas for April, 1924, printed in Buenos Aires, announces on page 19 the publication of a work, by Doctor Anselmo Windhausen, entitled *Líneas Generales de la Constitución Geológica de la Región situada al Oeste del Golfo de San Jorge.* This is a volume of over 300 pages, containing numerous illustrations and maps. It describes the geological conditions at Comodoro Rivadavia in Argentina. We are promised a review in the next number of *Petróleos y Minas.*

F. H. LAHEE

THE ASSOCIATION ROUND TABLE

GEOLOGISTS-INTERNATIONAL PETROLEUM SHOW

When it was decided not to have a midsummer meeting of the American Association of Petroleum Geologists, the members of the Tulsa Geological Society were quick to realize the possibilities of the situation in connection with the International Petroleum Exposition and an invitation to come to Tulsa on October 6, 7, and 8 was sent out. Geologists and their wives (and wives to be) to the number of some three hundred persons accepted the invitation.

The only serious business on the program aside from the International Exposition was a meeting of the Research Committee of the Association, although, as it turned out, a few of the geologists did more hard work and considerable more walking on the golf links than they were accustomed to in their ordinary field activities.

The visitors registered in the lobby of the Y.M.C.A.

OFFICIAL PROGRAM

Monday, October 6: Qualifying rounds in golf tournament at Oakhurst Country Club. Visit Exposition; either afternoon or night, attend theater at Exposition grounds where state princesses may be seen in "Styles and Smiles of 1924." Meeting of Research Committee.

Tuesday, October 7: Ladies tea, 3:00–4:30 P.M., at Oakhurst Country Club, for wives of members of Tulsa Geological Society and A.A.P.G. Play off during day in golf tournament at Oakhurst Country Club. Smoker, 8:00 P.M., at Virginia Grill, Boulder and Third streets, given by Mid-Continent Section of A.I.M.M.E. for their members, Tulsa Geological Society, and A.A.P.G. Theater party for visiting ladies of A.A.P.G. at Orpheum Theater.

Wednesday, October 8: Golf tournament finals. Cosden Refinery: Those desiring to visit Cosden Refinery will be taken through on request. Cars leave headquarters at 2:30 P.M. Dinner—entertainment and dance, 8:00 P.M., at Oakhurst Country Club, for members and wives of Tulsa Geological Society and A.A.P.G.

ASSOCIATION STARTS RESEARCH FUND

The Research Committee of the American Association of Petroleum Geologists met with representatives of the National Research Council, at which time an all-day session was held. There were present W. E. Wrather, chairman of the Association Committee and member of the National Council; David White and K. C. Heald, of the National Council; E. DeGolyer, of the Amerada Petroleum Corporation; W. T. Thom, Jr., of the United States Geological

Survey; and James H. Gardner, president of the Association and member of the Research Committee.

The most urgent needs of research in the field of petroleum geology were fully discussed and the whole matter boiled down to a practical working basis. The research being made by David White on "Source Beds of Petroleum and Experiments to Demonstrate the Origin of Oil" greatly impressed the Committee as being of vital importance and likely to lead to discoveries long sought by petroleum geologists. His tests on carbonaceous shale under measured furnace temperatures while being observed by the microscope are made possible by mechanical equipment for such work not heretofore discovered, but now in his possession in the laboratory of the National Research Council in Washington. Under heat and pressure observations will be made with the construction of charts and curves showing the conditions under which the soluble hydrocarbons (petroleum) are produced from the hydrogen and carbon contents of black shale. Such beds of shale occur in conjunction with oil-producing sands throughout the oil fields of the world, and as a result of his work it is highly probable that the facts surrounding the origin of oil under earth temperatures and pressures can be determined. High pressures and high temperatures for a short length of time are probably equivalent to low pressures and low temperatures through a long length of time.

In order that this work might go forward at once, a fund of $4,000 was made up among geologists of the Association. This will be the nucleus of a general fund of much larger proportions which the American Association of Petroleum Geologists will carry forward as opportunities arise. Other projects of research were classified which need financing and offer exceptional opportunities for moving certain theories over into the realm of established fact and bringing to light new discoveries of value to the petroleum industry.

GOLF TOURNAMENT

The entertainment provided by the Tulsa Geological Society for members of the American Association of Petroleum Geologists included a golf tournament held at Oakhurst Country Club and open only to members of the Association. Mr. James H. Gardner, president of the American Association, donated silver trophies to the winners as follows: a loving cup to the champion, a pitcher to the winner of B flight, and a serving-dish to the winner of C flight. The contestants were classified on the results of a qualifying round of 36-hole medal play on Monday, October 6, and the winners shot their way to the top in their respective classes in match play on Tuesday and Wednesday.

The championship flight included I. R. Sheldon, Wichita Falls; Dean Stacey and Frank Buttram, of Oklahoma City; F. E. Hutchinson, Houston; R. A. Reynolds, of Eastland, Texas; G. S. Dunlap, A. L. Beekley, and O. M. Edwards, of Tulsa. In this flight, I. R. Sheldon won the championship of the

Association, playing golf that would have carried him near the top in any tournament. He shot the difficult Oakhurst course in 77, which is within a few strokes of the course record. Dean Stacey played a splendid game and was a close second for championship honors.

T. K. Harnesberger, of Tulsa, won the Class B trophy by defeating R. Hughes, also of Tulsa, on the last hole of the match.

In Class C, Lewis Coryell, of Bristow, took the trophy by defeating John R. Suman, of Houston, in a close match.

While the men were golfing the ladies were given a tea at the Oakhurst Country Club on Tuesday afternoon by the committee composed of Mesdames E. W. McCrary, Richard Hughes, and Russell Tarr. Tuesday evening a theater party was held at the New Orpheum.

Tuesday night the Tulsa Section of the American Institute of Mining and Metallurgical Engineers took charge of the entertainment and put on a smoker at the Virginia Grill. Since most of the men present were members of all three organizations, they enjoyed the novel experience of being host and guest at the same time, and the toastmastership alternated between H. B. Goodrich and J. O. Lewis.

Talks were made by Frank W. DeWolf, D. W. Ohern, David White, George Otis Smith, Frank C. Greene, James H. Gardner, W. E. Wrather, E. L. DeGolyer, and Sidney Powers. Powers attempted to extend his long, prepared speech far over the time allotted, but was finally induced to give the floor.

James H. Gardner surprised everyone by abandoning his time-honored subject of cockroaches, both recent and fossil, for the subject of grasshoppers, and at the same time he overlooked the levity of the occasion and attempted to become serious. Because Mr. Gardner's activities alternate between the study of entomology and bringing in 1,000-barrel wells at Cromwell, he was dubbed "Bugs" Gardner.

E. L. DeGolyer made the only other speech of a serious nature. DeGolyer is a member of the Research Committee and he gave a report of the morning session. It seems that the Committee has engaged in two principal lines of researches—one has to do with increasing the size of plane table boards so that six can play at once; the other is an investigation of some means of opening an after-dinner speech in some other way than the hackneyed "That reminds me." Mr. DeGolyer gave some excellent illustrations of new methods which are not yet ready for the press.

The three days' entertainment was brought to a close Wednesday night. Through the courtesy of the Board of Managers of the Oakhurst Country Club, that Club set aside one of its strict rules and turned over the clubhouse to the geologists to the exclusion of its own members.

A turkey dinner, served to the accompaniment of a jazz orchestra and some songs, started the evening. The Marland quartet from Ponca City did con-

considerable roasting in spite of the theme of one of their songs: "We Ain't a-Goin' to Roast no Mo'."

James H. Gardner served as toastmaster, but had little opportunity to give one of his enlightening talks on the habits of cockroaches or grasshoppers, nor even on so small a subject as the flea.

Harry Nowlan made such a hit with his song-story of his own wanderings that he will never get through another meeting without a place on the program.

Frank W. DeWolf presented the Gardner trophies, and W. E. Wrather gave a short summary of the work of the Research Committee.

Dick Hughes then took the floor and attempted to defend his enumeration of the Tulsa members of the American Association, in which he stated that some one hundred and twenty-three members gave Tulsa as their residence, more than the next six cities combined. Before he had presented all his proofs, the window near him was forced open and six white-robed and masked figures stealthily grouped themselves around him before he realized what was happening. He was accused of wilfully misappropriating members of the American Association for the Tulsa Geological Society and, although he stoutly maintained his innocence, his accusers introduced so many of their witnesses that he was pronounced guilty and was about to be taken away bodily when the ex-governor of a prominent oil-producing state and the wife of the ex-governor of another prominent and adjoining oil-producing state, both noted for certain lines of activity, burst into the room, released the defendant, and seized his accusers. At the same time it was announced that the entire armed forces of the state would be called out if necessary. When unmasked it was found that one of the figures was a member of the Ethiopian race and one a "cloaks and suits."

The remainder of the evening was spent in dancing.

The committees in charge were: Reception—Frank Herald, W. B. Wilson, G. A. Kroenlein, Frank C. Greene, Richard Hughes; Dinner-Entertainment—A. F. Truex, Luther White, L. J. Zollers, Harry Nowlan; Golf Tournament—A. L. Beekley, S. S. Price, W. R. Hamilton; Ladies—Mesdames E. W. McCrary, Richard Hughes, Russell Tarr; Dinner-Arrangement—Luther Kennedy, F. G. Woodruff, Frank Clark; Auto Transportation—E. G. Woodruff.

FRANK C. GREENE

TULSA, OKLAHOMA

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following applicants for membership in the Association. This publication does not constitute an election, but places the names before the membership at large. In case any member has information bearing on the qualifications of

these applicants, please send it promptly to Charles E. Decker, Norman, Oklahoma.

(Names of sponsors are placed beneath the name of each applicant.)

FOR FULL MEMBERSHIP

Herschel H. Cooper, San Antonio, Texas
George D. Morgan, E. P. Hindes, Charles J. Wolford
Richard M. Dannenberg, Tulsa, Oklahoma
G. S. Rollin, T. K. Harnsberger, J. W. Merritt
Roy E. Dickerson, Manila, Philippine Islands
G. C. Gester, S. H. Gester, Reg. C. Stoner
George E. Dorsey, Tulsa, Oklahoma
Sidney Powers, R. J. Riggs, L. G. Keppler
Charles W. Henderson, Denver, Colorado
C. A. Fisher, Charles M. Rath, Thomas S. Harrison
Francis W. Hertel, Ventura, California
J. A. Taff, John F. Dodge, John B. Stevens
Ralph H. Mitchell, Thornton Heath, Surrey, England
T. O. Bosworth, F. W. Penny, A. Beeby Thompson
Calvin T. Moore, Oklahoma City, Oklahoma
Sidney Powers, Irving Perrine, W. C. Kite
Max Muehlberg, Aaran, Switzerland
O. M. Edwards, R. S. McFarland, Luther H. White
Desaix B. Myers, Los Angeles, California
Frank S. Hudson, N. L. Taliaferro, J. B. Case
William S. Russell, Vermillion, South Dakota
Roy A. Wilson, Freeman Ward, Charles Schuchert
Homer J. Steiny, San Francisco, California
J. A. Taff, John F. Dodge, John B. Stevens
Thomas L. Wark, San Francisco, California
J. A. Taff, John F. Dodge, John B. Stevens
Samuel H. Williston, Maracaibo, Venezuela
Edwin B. Hopkins, Albert D. Brokaw, H. Harper McKee

FOR ASSOCIATE MEMBERSHIP

John C. Barcklow, Tulsa, Oklahoma
L. Murray Neuman, A. W. Lauer, Robert H. Dott
Harry D. Kinney, Houston, Texas
Alexander Deussen, David Donoghue, F. E. Vaughan
Samuel S. Perry, Los Angeles, California
J. E. Elliott, F. C. Merritt, Roger F. White

FOREIGN MEMBERS

Petroleum geologists from countries other than the United States are constantly being added to our membership, thus giving the Association more and more an international scope. Recently the Executive Committee has received applications for full membership from nationals living in Mexico, Argentina, Holland, Switzerland, Canada, and London, England. One application of an Englishman is indorsed by members of the Association who are themselves his fellow-countrymen. In this connection it might be of interest to note that several of our members here in the States are also members of petroleum organizations in other countries, particularly of the British Institution of Petroleum Technologists, London.

The present administration is using its influence to extend its membership to include petroleum geologists of good standing everywhere, and we feel that at some time we should hold an annual meeting in New York to include a symposium on the geology of the oil fields of the world.

JAMES H. GARDNER

AT HOME AND ABROAD

HAROLD E. CULVER, of the Illinois State Geological Survey, attended the Birmingham meeting of the A.I.M.M.E.

GAIL F. MOULTON, of the Illinois State Geological Survey, has begun a systematic study of the oil-field waters in Illinois. Some of the oil-field problems appear to hinge upon detailed data of this character, and the results of Mr. Moulton's work are expected to facilitate other studies now in progress.

DOUGLAS M. COLLINGWOOD, of the Illinois State Geological Survey, has recently completed a study of the area adjacent to Decatur. A small amount of heavy black oil was recently found in some test wells here, and Mr. Collingwood's work indicates that some of this territory appears to justify more careful testing.

E. F. BULLARD, geologist with the Dixie Oil Company, has been transferred from the Tulsa, Oklahoma, office to the Shreveport, Louisiana, office of the company. Mr. Bullard was working in Texas, but since September he has been in the Louisiana-Arkansas territory.

ANGUS MCLEOD, located at Dallas as chief geologist of the Roxana Petroleum Corporation in the Mississippi Embayment district, was in Shreveport, Louisiana, in September.

S. C. STATHERS, chief geologist of the Standard Oil Company of Louisiana at Shreveport, Louisiana, was a visitor at the recent opening of the new Lake Charles gusher pool in Calcasieu Parish, Louisiana.

R. R. THOMPSON, chief geologist of the Texas and Pacific Coal and Oil Company at Thurber, Texas, made a business trip to the Shreveport, Louisiana, territory in September.

L. P. TEAS, chief geologist in the Shreveport, Louisiana, office of the Humble Oil and Refining Company, was in Atlantic City, New Jersey, and New York City in September and October, on account of the death of his father.

W. E. HOPPER, consulting geologist of Shreveport, Louisiana, recently made a three weeks' trip to Wyoming and Chicago.

H. S. RADE, formerly geologist with the Rycade Oil Corporation at Houston, Texas, is temporarily located at 70 Morningside Drive, New York, New York.

CHESTER WASHBURNE, of New York City, is continuing his study of faults in the Big Horn Basin, Wyoming, this fall.

As a result of the outcrop trip of the SHREVEPORT, LOUISIANA, SECTION of the Southwestern Geological Society last June, Midway Eocene fossils have been identified in samples collected along the Eocene-Cretaceous outcrop in southern Arkansas. Hitherto, the Midway formation has not been recognized at the outcrop in Arkansas farther southwest than Malvern, Hot Spring County; Localities where Midway fossils were found are near Emmett, Nevada County; Hope, Hempstead County; and at Buzzards' Bluff, Miller County, Arkansas. These discoveries may result in decreasing very considerably the known thickness of the Arkadelphia Cretaceous formation and in throwing more light on the faunal break between the Cretaceous and the Tertiary.

In relation to this problem, H. V. HOWE, head of the geological department at Louisiana State University, Baton Rouge, Louisiana, has resumed his extension course lectures at Shreveport under the auspices of the newly organized Shreveport Geological Society. The work for the fall term is on the Eocene formations.

H. P. BYBEE, associate professor of geology in the University of Texas at Austin, conducted his usual field geological work at Gainesville, Texas, the past summer. Before returning to the University, he spent some time in Indiana in September.

The geologists of the Shreveport, Louisiana, territory, which includes Lousiana, south Arkansas, and east Texas, formerly known as the Shreveport Section of the Southwestern Geological Society, have reorganized as an independent group in this tri-state area, and have adopted the name SHREVEPORT GEOLOGICAL SOCIETY. At the first meeting held October 3, at the Shreve Memorial, Shreveport, the following officers were elected: W. E. HOPPER, president, 311 Edwards Street; W. C. SPOONER, vice-president, Ardis Building; and H. G. SCHNEIDER, secretary-treasurer, Amerada Petroleum Corporation, Giddens-Lane Building—all of Shreveport.

FRANK BUTTRAM and family spent the summer in Northern Europe taking in the Cruise of the Midnight Sun. They visited Iceland, the North Cape and Nordland, Norway, Sweden, and the famous Fjord region. Returning they spent six weeks touring England and Scotland by automobile.

D. W. OHERN spent the summer in Marshalltown, Iowa.

JERRY B. NEWBY spent the summer in Bradford, Pennsylvania, where he is still doing geological work.

W. C. KITE spent the summer in Colorado with his family.

WILLIAM BUTTRAM has been working out of Terrell, Texas, for the last six months.

J. B. UMPLEBY studied flooding conditions in the Bradford, Pennsylvania, oil field during the summer.

IRVING PERRINE spent the summer in California in the Los Angeles region. He also made an extended trip into Baja California by automobile. Two wells are now drilling in Baja California: one at Johnson's Ranch, approximately 150 miles below the border, and the other about 350 miles below the border.

L. E. TROUT is spending most of his time supervising the drilling of several wells near Thornton, Texas, on a structure worked out by him.

L. RAY DAWSON spent the summer at Catalina Island, California. His present address is Archer City, Texas.

DEAN M. STACY spent a busy summer in Kansas and Oklahoma, making several short trips to Colorado, where his family spent the summer.

C. N. GOULD was recently appointed state geologist of Oklahoma and has been spending most of his time getting the survey in running condition again. He was with his family in Colorado for a part of the summer.

R. A. CONKLING made the trip to Toronto with the Oklahoma City Rotarians in June. He was in the field most of the summer.

Recent developments on the GULF COAST which are of interest to the geological profession are the bringing in of a new oil field at Lockport, near Lake Charles, Louisiana, and the finding of a new salt dome, 6 miles east of Damon Mound, in Fort Bend County, Texas.

The Lockport proposition was drilled by the Vacuum Oil Company and Gulf Refining Company of Louisiana, and their No. 1 Miller came in with an initial production of 3,000 barrels at 3,876 feet. A gas escape in the marsh was the first indication found in this territory. A negro trapper told some local residents of Lake Charles of the gas and it was then brought to the attention of the Vacuum Oil Company. S. A. THOMPSON, geologist for the Vacuum, examined the prospect and was favorably impressed.

The new dome is known as Nash and was found by the Rycade Oil Corporation. DONALD BARTON was shown some sulphur wells in this vicinity and placed the Rycade torsion balance on the ground. It seems to have registered for the Rycade's No. 1 Wisdom encountered dome materials at 640 feet.

At a recent meeting of the Houston Geological Society, JOHN R. SUMAN was elected president, MISS ALVA ELLISOR, vice-president, and DAVID DONOGHUE, secretary and treasurer.

PORTEUS BURKE and MR. KNIGHT of New Iberia, Louisiana, were in Houston recently. These gentlemen helped entertain those who took the New Iberia trip after the Houston meeting and they send their greetings to all those who were at the fish fry.

CHARLES LAWRENCE BAKER, of the East Coast Oil Company, Tampico, Mexico, was a visitor in Houston during September.

A. L. BALLARD, 417 Travis Building, San Antonio, Texas, is interested in several wildcat tests being drilled in the vicinity of San Antonio.

L. T. BARROW, formerly instructor in geology at the University of Texas, is now with the Humble Oil and Refining Company.

ALAN BRUYERE is in Kansas with the Texas Company. Mr. Bruyere has just returned to the States after four years' stay in Mexico with the Texas Company.

ROBERT S. BURG is with the Plateau Oil Company and is spending most of his time around San Antonio, Texas.

D. M. CASHIN, of the Southern Exploration Company, has moved his headquarters from Houston to Wichita Falls.

CHESTER M. CREBBS is general agent for the Venezuela Gulf Oil Corporation and is making headquarters at Maracaibo. The Gulf recently brought in a 5,000-barrel well at 1,880 feet in Lake Maracaibo.

A. E. FATH is with the Vacuum Oil Company in Texas.

A. E. HARTMAN has moved to San Antonio and has an office in the Travis Building.

JOHN R. ROBERTS, of the Oil and Gas Valuation Section, Bureau of Internal Revenue, made a hurried trip to the producing fields in south Texas during the month of September.

JOHN F. WEINZIERL is in charge of the siesmo exploring party that the Marland Oil Company is maintaining in the Gulf Coast district.

A. C. BIERMAN has an office in Dallas, Texas, and is specializing in appraisal work.

Colorado School of Mines offers a four-year curriculum in petroleum engineering, leading to the degree of P.E. (Petroleum Engineer). It is planned to give the student thorough practical knowledge which will enable him to go into either the production, the transportation, or the refining divisions of the petroleum industry.

JOHN M. MUIR, geologist for the Cia. Mexicana Holandesa at Tampico, Mexico, has returned recently from several months' vacation in Europe.

JOHN B. KERR, formerly with the Standard Oil Co., of Louisiana, has opened an office as consulting geologist at 601 Balboa Building, San Francisco, California. He has been working recently in the Midway and McKittrick districts of the San Joaquin Valley.

One of the recent foreign subscriptions to the *Bulletin* is from MEZHDUNARODNAYA KNIGA, Leningrad, Liteiny Prospect 53*a*, Russia.

CHARLES E. DECKER taught geology at Cornell University during part of the summer term. With Mrs. Decker he made the trip east and return by automobile.

D. R. SEMMES, assistant chief geologist of the joint geological department of the Aguila and Corona companies, Tampico, Mexico, has resigned his position and is returning to New York, where he expects to establish himself in a consulting capacity.

T. E. SWIGART has resigned his position as superintendent of the Bureau of Mines at Bartlesville, Oklahoma, to accept a position with the Shell Company, of California, with office in the Higgins Building, Los Angeles.

M. J. KIRWAN, who has long been associated with the Bureau of Mines, has been appointed superintendent of the Bartlesville station to succeed T. E. Swigart.

PHIL B. DOLMAN, associated with the Carter Oil Company for the past six years, has lately returned from a four months' tour of the oil fields and areas of prospective interest in the western states. Mr. Dolman has entered consulting practice in the capacity of mining engineer and petroleum geologist with offices in the National Bank of Commerce Building, Tulsa, Oklahoma.

SOPHIA WHITEHEAD, wife of Robert Brooks Whitehead, chief geologist of the Atlantic Oil Producing Company, Dallas, Texas, died September 10, 1924. Mrs. Whitehead received her A.B. degree from Texas University in 1917, and was a member of Kappa Alpha Theta Sorority. She is survived by her husband, and son, Robert Brooks, Jr.

MRS. DEWITT T. RING died at Buffalo, New York, on September 10, 1924.

JOHN L. RICH enjoyed some weeks' vacation in New York during September and October.

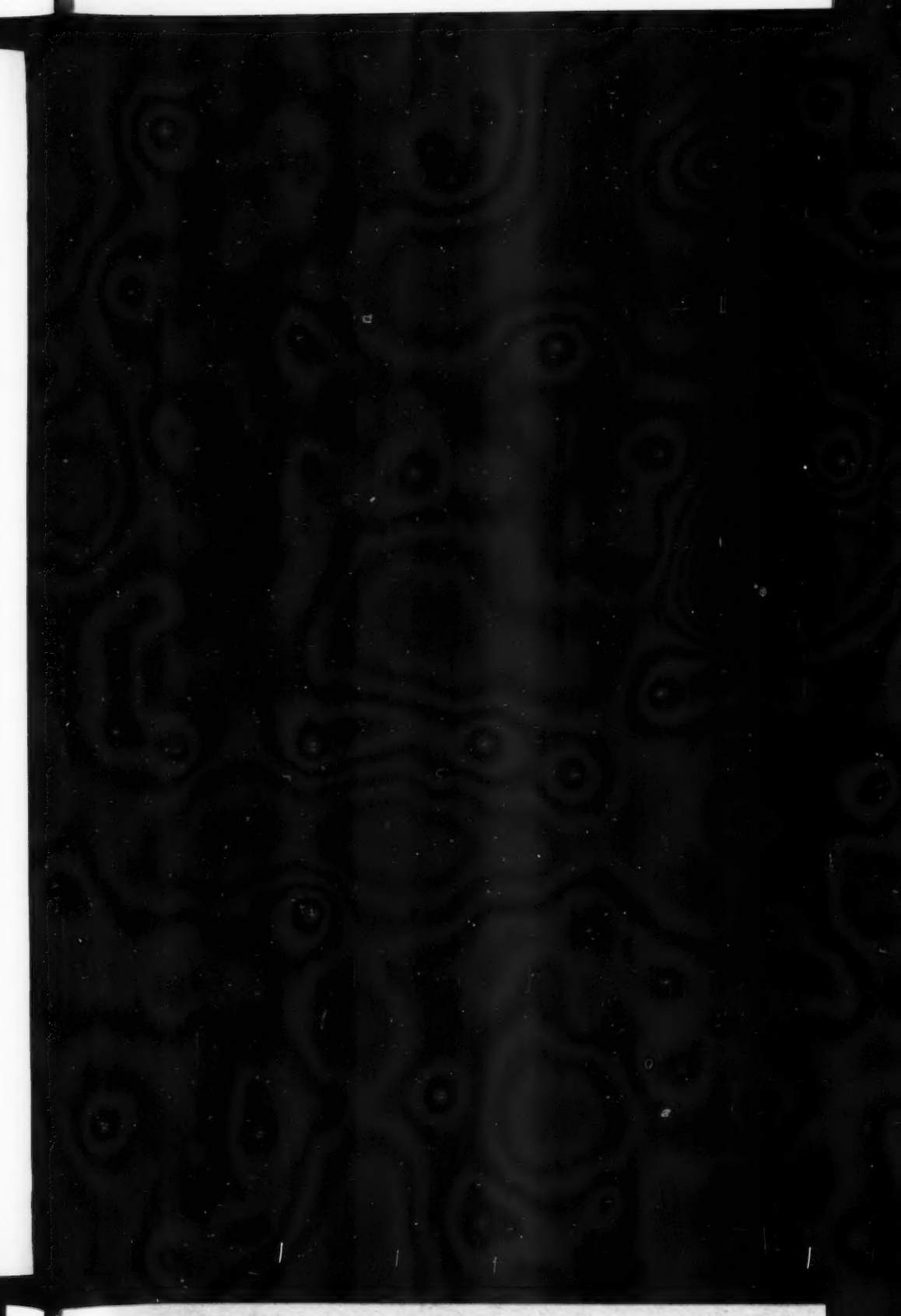
DWIGHT H. THONBURG, geologist for the Roxana Petroleum Corporation, is in Basel, Switzerland, where during the present academic year he will attend the University of Basel.

FRANK A. HERALD, of Tulsa, Oklahoma, visited Shreveport and Dallas in August, in the interest of Herald Brothers' acreage in Bowie County, Texas.

LESLIE STEELE HARLOWE underwent an operation for appendicitis in August at Shreveport, Louisiana, and has resumed his work in the geological department of the Louisiana Oil Refining Corporation.

GEORGE A. KROENLEIN, chief geologist for the Gilliland Oil Company at Tulsa, Oklahoma, visited the company's producing properties in Arkansas and Louisiana in September.

GERALD M. PONTON, manager of the Harris Oil Corporation, Ltd., Toronto, Canada, is returning to Ontario in September as the head of a syndicate inter-

ested in gold and silver mining in the provinces of Ontario, Quebec, and Manitoba. Mr. Ponton produced the first oil in Webster Parish from the Lloyd Harris *et al.*—Pine Woods No. 3, the discovery well (August, 1922) of the Sarepta pool, from which one well a total of 40,000 barrels of oil has been shipped during the past year (September, 1923, to September, 1924). This well, when choked down to $\frac{7}{8}$-inch opening, clears daily 9,700,000 cubic feet of dry gas, which from now on will be produced instead of the oil.

A. F. CRIDER, head of the geological department of the Dixie Oil Company at Shreveport, Louisiana, spent his vacation in September with his family touring Tennessee and Kentucky, and returning through Rolla, Missouri, where his son is entering college.